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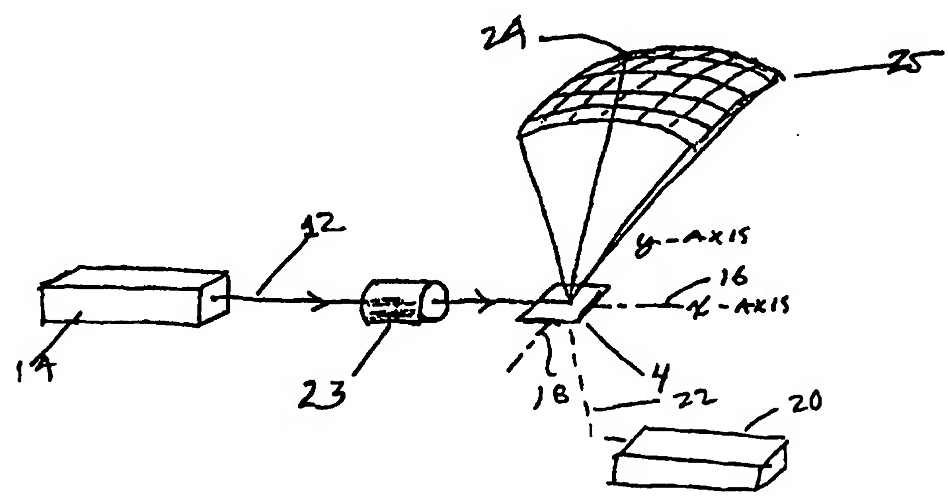

(57) Abstract

A dual axis single mirror microelectromechanical scanner is used in place of multiple single axis, single mirror optomechanical or electro/acoustooptic scanners for scanning image areas in various devices such as large screen projection televisions, direct retinal scan displays, facsimile machines, document scanners, bar code scanners, laser light show displays, oscilloscopes, xero/photographic reproduction and stereophotolithography devices. The dual axis single mirror microelectromechanical scanner is inexpensive, extremely small and requires very low power.

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Description

METHOD AND APPARATUS FOR OPTICAL SCANNING

Technical Field

The present invention pertains to optical scanners and methods for their use, and more specifically, to a mirror scanner adapted to scan in two axes and to methods for its use.

Background of the Invention

Generally, optical scanning systems for scanning in multiple (two or more) axes are composed of two or more single axis scanning devices which can be independently scanned in at least two orthogonal directions. Systems such as these are used in direct retinal scan displays, such as those disclosed in two patents. One of these patents is United States Patent No. 5,369,415, filed June 29, 1992 by Richard et al and entitled "Direct Retinal Scan Display with Planar Imager". The other patent is United States Patent No. No. 5,359,669, filed April 13, 1992 by Shanley et al, and entitled "Remote Retinal Scan Identifier".

At present, it is necessary to use two single axis scanners (for example, mechanical, electro- or acousto-optic scanners) to scan in two orthogonal directions. Such scanning is required to produce the scanning raster needed to generate (in the case of reproduction) or dissect (in the case of reading) an image. Using multiple single axis scanners requires substantial amounts of power and apparatus, which results in a large, expensive and unwieldy structures.

Dual axis scanning systems utilizing single mirrors have been devised, as for example the scanning mirror disclosed by Goto, et al, in U.S. Patent 5,097,354. Because of the fabrication techniques utilized, the devices are unable to operate at large scanning angles and frequencies which are required for most applications such as real time television displays.

A dual axis single mirror scanner fabricated using microelectronic integrated circuit (commonly referred in the art

as Micro Electro Mechanical Systems, or MEMS) techniques is disclosed in the patent application "Microelectromechanical Television Scanning Device and Method for Making the Same", Johnson, Application No. 08/093,580, filed July 19, 1993.

Summary of the Invention

The present invention is useful to provide a new and improved method and apparatus for optical scanning. Particular applications of the present invention are as large screen television displays, direct retinal scan displays, facsimile machines, document scanners, bar code scanners, laser light show displays, information storage devices, xero/photographic reproduction devices, and stereophotolithography devices. The present invention also provides a new and less complicated method and apparatus for producing or dissecting an image. In addition, the present invention provides a new and improved method and apparatus of optical scanning for endoscopic purposes by providing a device that has a smaller diameter than is currently possible with fiberoptic bundles or miniature video endoscopes without compromising the resolution of the endoscopic image.

The above problems can be solved and the forgoing purposes realized by using a dual axis single mirror scanner. The mirror in the single mirror scanner can be microelectromechanical, i.e., fabricated in a similar manner (and with similar techniques) as used to produce microelectronic integrated circuits. The size and mass of the mirror are chosen so that the scanner is capable of scanning at extremely high frequencies (15 to 20 kHz) and through large dual axis scanning angles (> 90 degrees) with a minimum of power. Additionally, since the scanner is fabricated using MEMS techniques, it is extremely inexpensive and may be mass produced in large quantities. Therefore, the use of the dual axis single mirror microelectromechanical scanner in the applications described above will reduce the overall cost of the end use devices.

According to one aspect, the invention is a scanner comprising a mirror and an optical element. The mirror is adapted to reflect light received from a predetermined receive direction, and the orientation of the mirror being controllable in two dimensions in response to control signals. The optical element optically transforms the light.

According to another aspect, the invention is an image scanner. The image scanner comprises a mirror, an optical element, and a control circuit. The mirror is adapted to reflect light received from a predetermined receive direction, and the orientation of the mirror is controllable in two dimensions in response to control signals. The optical element optically transforms the light. The control circuit produces the control signals.

According to a still further aspect, the invention is an image scanner. The image scanner comprises a plurality of scanners. Each scanner includes a mirror and an optical element. The mirror in each scanner is adapted to reflect light received from a predetermined receive direction, and the orientation of the mirror is controllable in two dimensions in response to control signals. The optical element in each scanner optically transforms the light. The control circuit produces control signals for each scanner in the plurality of scanners.

According to yet another aspect, the invention is a method for scanning light in a predetermined pattern. The method includes the steps of: a) placing a mirror at a position to receive the light from a predetermined direction, and b) connecting a control circuit to the mirror, the control circuit being responsive to a control signal. The method further includes the steps of: c) producing a control signal containing information representing the predetermined pattern, d) transmitting the control signal to the control circuit, thereby controlling the orientation of the mirror in response to the control signals, and e) optically transforming the light.

Brief Description of the Drawings

Figure 1 is a perspective schematic diagram of a first configuration of an apparatus in accordance with the invention.

Figure 2 is a perspective schematic diagram of a second configuration of an apparatus in accordance with the invention.

Figure 3 is a perspective schematic diagram of a third configuration of an apparatus in accordance with the invention.

Figure 4 is a perspective schematic diagram of a fourth configuration of an apparatus in accordance with invention.

Figure 5 is a perspective schematic diagram of a fifth configuration of an apparatus in accordance with the invention.

Figure 6 is a perspective schematic diagram of a sixth configuration of an apparatus in accordance with the invention.

Figure 7 is a perspective schematic diagram of a first embodiment of a television display using dual axis MEMS scanning mirrors in accordance with the present invention.

Figure 8 is a plan schematic diagram of a second embodiment of a television display using dual axis MEMS scanning mirrors in accordance with the present invention.

Figure 9 is a perspective schematic diagram of a first embodiment of a facsimile reproduction device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 10 is a perspective schematic diagram of a second embodiment of a facsimile reproduction device using dual axis MEMS scanning mirrors in accordance with the present invention.

Figure 11 is a perspective schematic diagram of a first embodiment of a xero/photographic reproduction device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 12 is a perspective schematic diagram of a second embodiment of a xero/photographic reproduction device using dual axis MEMS scanning mirrors in accordance with the present invention.

Figure 13 is a perspective schematic diagram of a laser display device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 14 is a perspective schematic diagram of an oscilloscope using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 15 is a perspective schematic diagram of a stereophotolithography device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 16 is a perspective schematic diagram of a laser cutting/sculpting device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 17 is a schematic diagram of a laser pointing device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 18 is a perspective schematic diagram of a holographic character generator using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 19 is a perspective schematic diagram of a flying spot scanner using dual axis MEMS scanning mirrors in accordance with the present invention.

Figure 20 is a perspective schematic diagram of an image scanner using dual axis MEMS scanning mirrors in accordance with the present invention.

Figure 21 is a perspective schematic diagram of a first embodiment of a flying spot scanner using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 22 is an elevational schematic diagram of a second embodiment of a flying spot scanner using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 23 is a perspective schematic diagram of a flying spot microscope using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 24A is a schematic diagram of a flying spot endoscope in accordance with the present invention.

Figure 24B is a perspective close-up schematic diagram of the flying spot endoscope of Figure 24A.

Figure 25 is a perspective schematic diagram of a television image pickup device using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 26 is a plan schematic diagram of a microscope scanner using a dual axis MEMS scanning mirror in accordance with the present invention.

Figure 27A is a schematic diagram of an endoscope scanner in accordance with the present invention.

Figure 27B is a perspective close-up schematic diagram of the endoscope scanner of Figure 27A.

Figure 28 is a perspective schematic diagram of a telescope scanner in accordance with the present invention.

Figure 29 is a perspective schematic diagram of a horizon scanner in accordance with the present invention.

Detailed Description of the Preferred Embodiment of the Invention

The common element in each of the following described embodiments is a single mirror optical scanner capable of being controlled along two non-parallel axes at high speeds and large angular excursions. This dual axis single mirror microelectromechanical scanner is fabricated using Micro Electro Mechanical System (MEMS) techniques known in prior art.

The following configurations are applicable to a variety of applications and each configuration is separately numbered for easier detailed description of the preferred embodiments hereinafter.

Referring to Figure 1, a single dual axis MEMS-fabricated mirror 4 is placed along a radiation path 12 defined by the light beam produced by a collimated, modulated radiation source 14 placed at a known location and directed at the mirror 4. The mirror 4 is adapted to be scanned about two non-parallel (and preferably orthogonal) axes, such as x-axis 16 and y-axis 18 which pass through or near the mirror 4.

The mirror 4 is controlled by a control device 20 which is connected to the mirror 4 through a link 22. The control device

20 can take the form of a dedicated electronic circuit or an electronic computer which is programmed to perform the control function. The link 22 to the mirror 4 can be an electromagnetic link, a magnetic link, a thermal link, or an electrical link as would be known by those skilled in the relevant arts.

Focusing optics 23 (such as an objective lens) is placed along the radiation path 12 between the source 14 and the single mirror 4 to focus the radiation from the source 14 at a desired spot 24 on a focus surface 25. The focus surface 25 is a curved array of such spots 24, which may be considered to be scannable picture elements (pixels) on the focus surface 25. This is known in the optical art as a post objective scanner and is particularly suitable for scanning the light received from a predetermined receive direction. This configuration will hereinafter be referred to as configuration 1. Aside from a conventional glass lens, the focusing optics 23 can take the form of a diffraction grating, a holographic optical element (HOE), and so forth.

Referring to Figure 2, a single dual axis MEMS-fabricated mirror 204 is placed along a radiation path 212 defined by the light beam produced by a collimated, modulated radiation source 214 placed at a known location and directed at the mirror 204. The mirror 204 is adapted to be scanned about two non-parallel (and preferably orthogonal) axes, such as x-axis 216 and y-axis 218 which pass through or near the mirror 204.

The mirror 204 is controlled by a control device 220 which is connected to the mirror 204 through a link 222. The control device 220 can take the form of a dedicated electronic circuit or an electronic computer which is programmed to perform the control function. The link 222 to the mirror 204 can be an electromagnetic link, a magnetic link, a thermal link, or an electrical link as would be known by those skilled in the relevant arts.

Focusing optics 223 are placed in the radiation path 212 after the mirror 204 to focus the radiation from the source 214 at a desired spot 224 on a focus plane 226. The focus plane 226

is a flat array of such spots 224, which may be considered to be scannable pixels on the focus plane 226. This is known in the art as a pre objective laser scanner and is also particularly suitable for scanning the light received from a predetermined receive direction. This configuration will be referred to as configuration 2. Aside from a conventional glass lens, the focusing optics 223 can take the form of a diffraction grating, a holographic optical element (HOE), and so forth.

Referring to Figure 3, a single dual axis MEMS-fabricated mirror 304 is placed along a radiation path 312 defined by the light beam produced by a collimated, unmodulated radiation source 314 placed at a known location and directed at the mirror 304. The mirror 304 is adapted to be scanned about two non-parallel (and preferably orthogonal) axes, such as x-axis 316 and y-axis 318 which pass through or near the mirror 304.

The mirror 304 is controlled by a control device 320 which is connected to the mirror 304 through a link 322. The control device 320 can take the form of a dedicated electronic circuit or an electronic computer which is programmed to perform the control function. The link 322 to the mirror 304 can be an electromagnetic link, a magnetic link, a thermal link, or an electrical link as would be known by those skilled in the relevant arts.

Focusing optics 323 (such as an objective lens) is placed along the radiation path 312 between the source 314 and the single mirror 304 to focus the radiation from the source 314 at a desired spot 324 on a focus surface 325. The focus surface 325 is a curved array of such spots 324 , which may be considered to be scannable pixels on the focus surface 325.

A stationary radiation detector 328 is oriented to receive radiation 337 which is reflected or transmitted by the focus surface 325. The radiation detector 328 produces a video signal 339 for eventual transmission, recording, and other forms of signal processing and handling. This is known in the art as a post objective flying spot scanner and is particularly suitable for scanning the light received from a predetermined receive

direction. This configuration will be referred to as configuration 3.

Referring to Figure 4, a single dual axis MEMS-fabricated mirror 404 is placed along a radiation path 412 defined by the light beam produced by a collimated, modulated radiation source 414 placed at a known location and directed at the mirror 404. The mirror 404 is adapted to be scanned about two non-parallel (and preferably orthogonal) axes, such as x-axis 416 and y-axis 418 which pass through or near the mirror 404.

The mirror 404 is controlled by a control device 420 which is connected to the mirror 404 through a link 422. the control device 420 can take the form of a dedicated electronic circuit or an electronic computer which is programmed to perform the control function. The link 422 to the mirror 404 can be an electromagnetic link, a magnetic link , a thermal link, or an electrical link as would be known by those skilled in the relevant arts.

Focusing optics 423 are placed along the radiation path 412 after the single mirror 404 to focus the radiation from the source 414 at a desired spot 424 on a planar surface 426. The planar surface 426 is a flat array of such spots 424, which may be considered to be scannable pixels on the planar surface 426.

A stationary radiation detector 428 is oriented to receive radiation 437, which is reflected or transmitted from the planar surface 426. The radiation detector 428 produces a video signal 429 for eventual transmission, recording, etc. This configuration produces a flat field of scanning pixels at the desired planar surface 426, and is known in the art as a pre objective flying spot scanner. This configuration will be referred to as configuration 4.

Referring to Figure 5, a single dual axis MEMS-fabricated scanner 504 is placed in use with a collimated radiation detector 508 directed at the mirror 504 in combination with focusing optics 513 placed along the radiation path 522 between the single mirror 504 and the detector 508. The detector 508 produces a video signal 529 for eventual transmission,

recording, etc. A light source 540 illuminates objects in the field of focus 545 with radiation 550 of suitable wavelength for detection by the radiation detector 508. In use, this configuration produces a field of focus 545 which is curved. The mirror 504 is controlled by a controller 560 which is connected to the mirror 504 by a link 562. The controller 560 can, for example, be a dedicated electronic circuit or an electronic computer programmed to perform the control function. The link 562 can be an electromagnetic link, a magnetic link, a thermal link, or an electrical link as would be known by those skilled in the relevant arts. This configuration is known in the art as a post objective image dissector, and will be referred to as configuration 5 hereinafter.

Referring to Figure 6, a single dual axis MEMS-fabricated mirror 604 is placed in use with a collimated radiation detector 608 directed at the mirror 604 in combination with focusing optics 613 placed in the radiation path 612 between the single mirror 604 and a field of focus 616. The radiation detector 608 produces a video signal 619 for eventual transmission, recording, etc. A light source 640 illuminates objects in the field of focus 616 with radiation 641 of suitable wavelength for detection by the radiation detector 608. This configuration produces a flat field of focus 616. The mirror 604 is controlled by a controller 650 which is connected to the mirror 604 by a link 652. The controller 650 can, for example, be a dedicated electronic circuit or an electronic computer programmed to perform the control function. The link 652 can be an electromagnetic link, a magnetic link, a thermal link, or an electrical link as would be known by those skilled in the relevant arts. This is known in the art as a pre objective image dissector. This configuration will be referred to as configuration 6.

The device configurations 1 through 4 may use a radiation source that is coherent (e.g., a fiber laser) or incoherent (e.g., a light emitting diode). The coherent fiber laser source can be chosen from the classes of 1) fiber lasers made from

fluorozirconate glass doped with thulium for room temperature emission of 455 nm (blue-violet) light (ref. Room-temperature Continuous-wave Upconversion Laser at 455 nm in a Tm3+ Fluorozirconate Fiber, M.P. LeFlohic, et al., Opt. Lett., Vol. 19, No. 23, Dec. 1, 1994), 2) fiber lasers of the fluorozirconate glass category doped with thulium for room temperature emission of 480 nm (blue) light and 3) fiber lasers of the fluorozirconate glass category doped with praseodymium for room temperature emission of 490 nm (blue-green), 520 nm (green), 605 nm (reddish-orange) and 635 nm (red) light (ref. Laser Diode-pumped Visible Upconversion Fiber Lasers, D. Piehler, et al., Proc. CLEO '93, Paper CThF3). Various doping and laser pumping schemes have been developed in prior are and are well understood. These fiber lasers provide a particularly compact, inexpensive and robust source of primary color (i.e. 480, 520 and 635 nm) laser radiation.

Additionally, the device configurations 1 through 4 may use a radiation source 1 where the frequency of the radiation source ranges from gamma radiation, through the visible spectrum to microwave electromagnetic radiation, and including ultrasound and sonic acoustic radiation frequencies.

The device configurations 3 through 6 may use radiation detectors which are sensitive to ranges from gamma radiation, through the visible spectrum to microwave electromagnetic radiation, and including ultrasound and sonic acoustic radiation frequencies. In the case of configurations 3 and 4, the corresponding radiation detector is typically matched in sensitivity to the radiation emitter. In the case of configurations 5 and 6, the radiation detector is typically matched in sensitivity to the radiation emitted or reflected from the object or scene being scanned.

The combination specified in configurations 1 or 2 may be used in a large screen projection television display system. Referring to Figure 7, typically, the light source for such a television display system 700 would be a single collimated color visible laser 701 (for monochrome) or three collimated color

(e.g., red, blue and green) visible lasers 701 (for full color) modulated by one or more electro-optic, acousto-optic modulators 712, or by direct modulation of the laser(s) 701. The preferred embodiment uses the Scophony system (ref.: The Supersonic Light Control and Its Application to Television With Special Reference to the Scophony Television Receiver, D.M. Robinson, Proc. of the IRE, pp. 483 - 486, Aug. 1939, The Design and Development of Television Receivers Using the Scophony Optical Scanning System, J. Sieger, Proc. of the IRE, pp. 487 - 491, Aug. 1939, Some Factors Involved in the Optical Design of a Modern Television Receiver Using Moving Scanners, H.W. Lee, Proc. of the IRE, pp. 496 - 500, Aug. 1939, A Television Display Using Acoustic Deflection and Modulation of Coherent Light, A. Korpel, et al., Applied Optics, pp. 1667 - 1674, Vol. 5, No. 10, Oct. 1966) of pixel storage in an acousto-optic modulator 712. Two complete optical systems are used in the television display system 700 since the pixel storage capacity of the acousto-optic modulator 712 is only half of a single horizontal scan in conventional television. Thus, the horizontal line scan is accomplished in two parts. Once the laser source(s) 701 is properly modulated, the beam is passed through a focusing optical element (diffractive, reflective, gradient index refractive or conventional refractive) (not specifically shown) in the modulator 712 as in the case of configuration 1. The optics are corrected to produce a flat field of pixels on the translucent vertical back projection screen 713. Next the beam is reflected off a single dual axis MEMS-fabricated scanning mirror 714. The appropriate horizontal and vertical scanning rate signals are applied to actuators connected to the mirror 714 as required to tilt the mirror 714 to generate a pixel pattern at the appropriate frame and field rates using the Scophony techniques well established in the art. The focused pixel elements finally project onto the translucent back projection screen 713 for viewing by an observer. The screen 713 may be translucent or reflective, curved or flat to varying degrees in relation to the final desired viewing illumination and configuration.

The combination specified in configurations 1 or 2 may also be used in a direct retinal scan display device. Configuration 2 is preferred since the final beam path is a converging path that enters into the cornea of the observer. Referring to Figure 8, typically, a light source 801 for such a device would be a single collimated color visible laser (for monochrome) or three collimated color (e.g., red, blue and green) visible lasers (for full color) modulated by an electro-optic, acousto-optic modulator (not shown) or by direct modulation of the laser(s). Visible upconversion fiber lasers (discussed above) are an excellent choice for this application. The light source 801 is contained in the remote assembly 817, which specifically contains the electronics and laser light sources. A combination fiber optic and electrical cable 818 conveys visible light modulation signal and actuator drive signals for the x/y axis MEMS -fabricated scanning mirror(s) 824. The beam(s) 832 is collimated by optics in the light source 801 and is reflected off the dual axis MEMS-fabricated scanning mirror 824. The appropriate horizontal and vertical scanning rate signals are applied to actuators of the mirror(s) 824 as required to tilt the mirror(s) 824 to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the light beam 845 (which is reflected from the mirror 824) is reflected in the proper raster pattern, the beam 845 is reflected off a focusing optical element 853 (reflective-diffractive, gradient index reflective or conventional reflective) as in the case of configuration 2. This produces a flat field of focused pixel elements 859 in the optical element 853. The focused pixel element beams 865 pass through the cornea of the observer, into the eye and generate an image directly on the retina 869 of the observer. As shown in Figure 8, two sets of direct retinal displays may be mounted on a single eyeglass style support 876, resting on the observer's head 880, to produce a monoscopic view (with single channel video information) or a stereoscopic view (with stereoscopic i.e., left and right image video information).

The combination specified in configurations 1 or 2 may be used in a facsimile reproduction device 900, as shown in Figure 9. Configuration 2 is preferred since the final pixel field is flat. Referring to Figure 9, typically, the light source 901 for the device 900 would be a single collimated laser modulated by a conventional electro-optic, acousto-optic modulator (not shown) or by direct modulation of the laser. The modulator is built-in to the light source 901 and controlled by a remote source of image generation information 923. The frequency of the radiation 932 by the laser should be matched to the maximum response of the sensitized material 941 used for recording (e.g., an infrared (IR) laser for heat sensitive paper). Once the laser source 901 is properly modulated, the beam 932 is reflected off the dual axis MEMS-fabricated scanning mirror 944. The appropriate horizontal and vertical scanning rate signals are applied to actuators connected to the mirror 944 as required to tilt the mirror 944 to generate a raster pattern 952 at the appropriate frame and field rates using techniques well established in the art. Once the light beam 932 is reflected in the proper raster pattern, the beam is passed through a focusing optical element 953 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 2. This deflected beam 962 produces a flat field of focused pixel elements 964 on the sensitive recording media 941 (e.g., thermal facsimile paper) and records the desired image.

Figure 10 illustrates a method of increasing the overall resolution at the surface of the sensitive recording media 941. Since the resolution of a mirror scanning system is fixed with respect to the limiting aperture (typically the size of the mirror) and the overall scanning angle, it is possible to increase resolution of such a system by increasing the number of scanning systems and decreasing the distance of each system from the sensitive recording media 941. In Figure 10, four systems of the type illustrated in Figure 9 are used to increase the

resolution at the sensitive recording media 941 by a factor of four.

The combination specified in configurations 1 or 2 may be used in a xero/photographic reproduction system. Configuration 2 is preferred since the final pixel field 962 is flat on the surface of the xerographic plate 24 or photographic film 26. Referring to Figure 11, typically the light source 1110 for such a device is a single collimated laser modulated by an electro-optic, acousto-optic modulator (not shown) or by direct modulation of the light source 1110 in the case of a xerographic or monochrome photographic system or a set of three color lasers (red, blue and green). Laser modulation is controlled by a either scanner information 1125 or computer generated data 1127 which are transmitted to the light source 1110 over a cable 1130. The frequency of the light beam 1132 by the laser should be matched to the maximum response of the sensitized material 1135 used for recording (e.g., green laser for a xerographic plate). Once the light source 1110 is properly modulated, the light beam 1132 is reflected off the dual axis MEMS-fabricated scanning mirror 1134. The appropriate horizontal and vertical scanning rate signals are applied to actuators (not shown) attached to the scanning mirror 1134 as required to tilt the scanning mirror 1134 to generate a raster pattern 1152 at the appropriate frame and field rates using techniques well established in the art. Once the light beam 1132 is reflected in the proper raster pattern, it passes through a focusing optical element 1136 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 2. This deflected beam 1150 produces a flat field of focused pixel elements 22 (see Figure 2) on the xerographic plate 1135 (or a color film plate) and records the desired image. This produces a flat field of focused pixel elements 22 on the xerographic plate 1135 (or color film plate) and records the desired image for eventual processing and fixation to a suitable substrate (e.g., paper or positive color film). In the case of a color

photographic recorder, the sensitive material may be color negative or positive film which is opaque or transparent.

Figure 12 illustrates a method of increasing the overall resolution at the surface of the xerographic plate 1135 (or color film). Since the resolution of a mirror scanning system is fixed with respect to the limiting aperture (typically the size of the mirror) and the overall scanning angle, it is possible to increase resolution of such a system by increasing the number of scanning systems and decreasing the distance of each system from the xerographic plate 1135 (or color film). In Figure 12, four systems of the type illustrated in Figure 11 are used to increase the resolution at the xerographic plate 1135 (or color film) by a factor of four.

The combination specified in configurations 1 or 2 may be used in a laser light show display 1300. Referring to Figure 13, the light source 1301 for such a device can be a single collimated laser which may be modulated by an electro-optic, acousto-optic modulator (not shown) or by direct modulation of the laser. The light source 1301 does not necessarily have to be modulated. Once the light source 1301 is properly modulated (if desired), the beam 1302 is passed through a focusing optical element 1310 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 1. This will eventually produce a curved field of focused pixel elements 28 in the field 1330. Next the beam 1302 is reflected off the dual axis MEMS-fabricated scanning mirror 1340. The appropriate horizontal and vertical positioning information signals 1147 are applied to actuators (described above) which actuate the scanner 1340 as required to tilt the scanner 1340 to project a vectored pattern 1358 at the desired surface 1359 using techniques well established in the art. Once the light beam 1302 is reflected in the proper vectored pattern, the beam 1360 may be passed through a focusing optical element (not shown) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 2 (not illustrated). This produces a flat field of focused pixel

elements in a vectored pattern 1358 at the desired surface 1359. The beam 1360 is finally projected onto the surface 1359, into suspended particles, etc. to generate the desired light pattern 1358 for observation by an audience. As seen in Figure 13, the vectored pattern 1358 is a vectored pattern with a path, as generally indicated by arrows 1362. This is in contrast to an image generated by a scanning raster. The light source 1301 in this device may consist of many different colored lasers or a combination of red, blue and green lasers to produce a full spectrum of colors in the display 1358.

The combination specified in configurations 1 or 2 may be used in an oscilloscope 1400. Referring to Figure 14, the light source 1401 for such an oscilloscope 1400 would be a single collimated laser which may be modulated by an electro-optic, acousto-optic modulator (not shown) or by direct modulation of the laser. The light source 1401 does not necessarily have to be modulated. Once the light source 1401 is properly modulated (if desired), a light beam 1402 is passed through a focusing optical element 1403 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 1. This will eventually produce a curved field 1431 of focused pixel elements. Next, the beam 1402 is reflected off the dual axis MEMS-fabricated scanning mirror 1434. The appropriate vertical (usually the signal to be visualized) and horizontal (usually the time sweep) positioning information signals 1437 and 1438, respectively, are applied to the actuators for the scanner 1434 as required to tilt the mirror 1434 to project a vectored pattern 1432 at the desired curved field 1431 using techniques well established in the art. Once the light beam 1402 is reflected in the proper vectored pattern 1450, the beam may be passed through a focusing optical element (not shown) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 2 (not shown). This produces a flat field of focused pixel elements. The focused pixel elements are finally projected onto the translucent or opaque screen 1431 to generate the desired

oscilloscope tracing 1432. The screen 1431 may contain a grid 1433 or any desired pattern for aiding in the interpretation of the oscilloscope tracing 1432. The screen 1431 is mounted on a hinge 1454 which is attached to the base 1455 of the unit. This allows for compact storage of the device when not in use. The light source 1401 in this device may consist of many different colored lasers or a combination of red, blue and green lasers to convey additional information in the oscilloscope tracing 1432.

The combination specified in configuration 2 may be used in a stereophotolithography device 1500. Referring to Figure 15, the light source 1501 for such a device would be a single collimated UV emitting laser which may be modulated by an electro-optic, acousto-optic modulator (not shown) or by direct modulation of the laser. The modulation signals 1527 are supplied from a computer 1530 in synchrony with the mirror positioning information (also in signals 1527). Once the beam 1502 produced by the light source 1501 is properly modulated, the beam 1502 is reflected off the dual axis MEMS-fabricated scanning mirror 1504. The appropriate computer generated horizontal and vertical positioning information signals 1527 are applied to the actuators of the mirror 1504 as required to tilt the mirror 1504 to project a vectored pattern 1550 at the desired surface 1538 using techniques well established in the art. Once the light beam 1502 is reflected in the proper vectored pattern 1550, the beam 1502 is passed through a focusing optical element 1503 (diffractive, reflective, gradient index refractive or conventional refractive). This produces a flat field of focused pixel elements at the surface 1538 of a UV sensitive photopolymerized polymer. The UV light beam 1550 is scanned over the surface 1538 of the photopolymer in the areas where solid plastic is desired. The solid plastic 1539 rests upon either a table 1540 immersed in the surface 1538 of the photopolymer and slightly below the surface 1538 of the photopolymer or upon the last solidified plastic layer 1539. Upon completion of the desired scan for a particular layer, the table 1540 (immersed in the photopolymer and below the plane of laser activity) is

lowered incrementally in the photopolymer vat 1542 for the next scanning layer construction by an actuator 1541. After all the desired layers are complete, a solid layer 1539 results corresponding to the information received from a Computer Aided Design (CAD) data file. The basic principles of stereophotolithography are well known in the art.

The combination specified in configurations 1 or 2 may be used in a laser cutting/sculpting device 1600. As illustrated in Figure 16, the light source 1601 for such a device would be a single collimated IR emitting laser which may be modulated by an electro-optic, acousto-optic modulator or by direct modulation of the laser. The light source 1601 does not necessarily have to be modulated. Once the laser source 1601 is properly modulated (if desired), the beam 1602 is passed through a focusing optical element (not shown) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 1. This will eventually produce a curved field of focused pixel elements. The beam 2 is then reflected off the dual axis MEMS-fabricated scanning mirror 1604. The appropriate horizontal and vertical positioning information signals 1627 are applied to the actuators of the scanning mirror 1604 as required (e.g., from a computer CAD file) to tilt the mirror 1604 to project a vectored pattern 1615 at the desired surface 1643 using techniques well established in the art. Once the light beam 1602 is reflected in the proper vectored pattern, the beam 1602 is passed through a focusing optical element 1603 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 2. This produces a flat field of focused pixel elements. The focused pixel elements are finally projected onto the desired workpiece 1643 where the IR light beam ablates or vaporizes the material that is to be removed. The illustration shows material being ablated away from a substrate 1644.

The combination specified in configurations 1 or 2 may be used in a laser pointer device 1700. As illustrated in Figure 17, the light source 1701 for such a device would be a single

collimated unmodulated laser. The collimated light beam 1702 is passed through a focusing optical element 1703 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 1. This will eventually produce a curved field of focused pixel elements. Next the beam 1702 is reflected off the dual axis MEMS-fabricated scanning mirror 1704. The appropriate horizontal and vertical positioning information signals 1727 (which may be generated by a joystick or computer, for example) are applied to the actuators of the mirror 1704 as required to tilt the mirror 1704 to project a light spot in a path 1728 or point (not illustrated) at the desired surface 129. Once the light beam 1702 is reflected off the dual axis MEMS-fabricated scanning mirror 1704 the beam may be passed through a focusing optical element (not illustrated) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 1702 (not illustrated). This produces a flat field of focused pixel elements. The focused pixel elements 1715 are finally projected onto the desired surface 1729 to generate the desired light pointer pattern 1728 or spot. The light source 1701 in this device may consist of many different colored lasers or a combination of red, blue and green lasers to produce a full spectrum of colors in the pointer pattern 1728 or spot. Also illustrated in Figure 17 is an image 1746 projected from an image projector 1745 via projection beams 1747. An audience 1730 is able to clearly see the portions of the image 1746 outlined by the light beam tracing 1728.

The combination specified in configurations 1 or 2 may be used in a holographic character generator 1800. As illustrated in Figure 18, the light source 1801 for such a generator 1800 would be a single collimated unmodulated laser. The collimated light beam 1802 is passed through a focusing optical element 1803 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 1. If this configuration is used it will eventually produce a curved field of focused pixel elements. Next the beam 1802 is reflected

off the dual axis MEMS-fabricated scanning mirror 1804. The appropriate horizontal and vertical positioning information signals 1827 (which may be generated by a computer data file, for example) are applied to the actuators of the mirror 1804 as required to tilt the mirror 1804 to project a light spot 1849 at the desired position on a holographic plate 1848 containing character generating holographic optical elements. Once the light beam 1802 is reflected off the dual axis MEMS-fabricated scanning mirror 1804 the beam 1802 may be passed through a focusing optical element (not shown) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 2 (not illustrated). If this configuration is used it produces a flat field of focused pixel elements. The focused pixel element 1849 is finally projected through the holographic plate 1848 containing holographic character generating patterns. This method of holographic character generation is well known in the art. The individual holographic character optical elements then focus the laser light to a common conjugate point at a lens 1850 which relays the character light pattern to a single axis scanning mirror 1851. This mirror 1851 may direct the character generating light pattern through angle 1852 to a position on a light sensitive drum 1853 (e.g., a selenium xerography drum) where the character is formed. This device can be used in conjunction with a photographic or xerographic recording device for phototypesetting or high speed text printing applications. The most commonly used characters may be located at the center of the holographic plate for the fastest access by the scanning mirror. This would reduce the overall character accessing time required and increase the printing speed of the device.

The combinations specified in configurations 3 and 4 may be used in a document scanner or facsimile scanner device 1900. The configurations using combinations 3 and 4 are considered flying spot document scanners in the art. Referring to Figure 19, the light sources 1901 for this device would be collimated unmodulated lasers powered by power supply 1957. The collimated

light beam 1902 may be passed through a focusing optical element (not shown) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 3 (not illustrated). This will eventually produce a curved field of focused pixel elements. Next the beam 1902 is reflected off the dual axis MEMS-fabricated scanning mirror 1904. The appropriate horizontal and vertical scanning rate signals are applied to the actuators for the mirror 1904 as required to tilt the mirror 1904 to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the light beam 1902 is reflected in the proper raster pattern, the beam 1902 is passed through a focusing optical element 1903 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4. This produces a flat field of focused pixel elements. The focused pixel elements 1922 are finally projected onto the desired object surface (e.g., a document) 1955 and scanned in the raster pattern 1922. The light source 1901 in this device 1900 may consist of a single color lasers or a combination of red, blue and green lasers to illuminate in a full spectrum of colors in the raster 1922. The intensity of the light reflected off the object 1956 at the spot focus point is in accordance with the reflectivity of the surface of the object 1955. This reflected light 1956 is collected by a photoelectric detector 1954 which generates an image signal for further processing by electronics (e.g., converted into a digital signal). Figure 19 illustrates a set of four scanners arranged for resolution enhancement.

The combinations specified in configurations 5 and 6 may be used in a document scanner or facsimile scanner device 2000. The configurations using combinations 5 and 6 are considered image dissector document scanners in the art. Referring to Figure 20, the light source 2058 for this device would be a white light source located externally to the scanning device 2000. The white light 2015 is directed at the object 2055 (e.g., a document) being scanned to evenly illuminate the object 2055. The

collected light 2056 is passed through a focusing optical element 2003 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 5. This will eventually produce a flat field of focused pixel elements 2022. Next, the collected light 2056 is reflected off the dual axis MEMS-fabricated scanning mirror 2004. The appropriate horizontal and vertical scanning rate signals are applied to the actuators for the mirror 2004 actuators as required to tilt the mirror 2004 to generate a raster pattern 2022 at the appropriate frame and field rates using techniques well established in the art. Once the received light 2056 is reflected in the proper raster pattern 2022, the now stationary beam 2002 is passed through a focusing optical element (not illustrated) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4 (not illustrated). This produces a curved field of focused pixel elements. The beam 2002 is finally collected by an appropriately sensitive detector 2054. The light source 2058 in this device may consist of a single color (for monochrome) or a combination of red, blue and green lights sequentially displayed which produce a full color data signal. Additionally, a single (for monochrome) or multiple (e.g., red, green and blue sensitive) detectors may be used in any of the above combinations to produce a data signal. The material being scanned 2055 may be opaque or transparent in any of the above combinations.

The combination specified in configurations 3 and 4 may be used in a flying spot slide or cinematography television scanner 2100. As illustrated in Figure 21, the light source 2101 for this device would be a collimated unmodulated laser powered by a power supply 2157. The collimated light beam 2102 is passed through a focusing optical element (not illustrated) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 3 (not illustrated). This will eventually produce a curved field of focused pixel elements. Next, the beam 2102 is reflected off the dual axis MEMS-fabricated scanning mirror 2104. The appropriate

horizontal and vertical scanning rate signals are applied to the scanner 2104 actuators as required to tilt the mirror 2104 to generate a raster pattern 2122 at the appropriate frame and field rates using techniques well established in the art. Once the light beam 2115 is reflected in the proper raster pattern 2122, the beam 2102 is passed through a focusing optical element 2103 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4. This produces a flat field of focused pixel elements 2122. The focused pixel elements 2122 are finally projected through the desired object surface 2160 (e.g., a cinematography film 2161) and scanned in a raster pattern 2122 . The light source 2101 in this device may consist of a single color laser or a combination of red, blue and green lasers to produce a full spectrum of colors at the focus point. The light transmitted 2156 through the transparency 2160 at the spot focus point is transmitted in accordance with the opacity/color of the transparency 2160 at the spot location. This transmitted light 2156 is collected by a radiation detector 2154 which generates an image signal 2162 for further processing by electronics (e.g., converted into a digital signal). A color signal may be generated in one of the following manners. First, the appropriately colored laser 2101 may be scanned in sequential fashion (i.e., red, blue, green, red, blue, etc.) through the transparency 2160 and the transmitted laser light 2156 detected by a single, panchromatic detector 2154 in serial fashion. Or, secondly, the tricolored lasers 2101 may be on at all times, scanned in a raster 2122 and three monochromatic (i.e. sensitive to red, blue and green light) detectors 2154 detect the laser light 2156 transmitted through the transparency 2160 in parallel fashion.

The combination specified in configurations 3 and 4 may be used in a flying spot ophthalmic retinal scanner 2200. As illustrated in Figure 22, the light source 2201 for this device would be a collimated unmodulated laser. The collimated light beam 2202 is passed through a focusing optical element 2203 (diffractive, reflective, gradient index refractive or

conventional refractive) as in the case of configuration 3. This will eventually produce a curved field of focused pixel elements. Next, the beam 2202 is reflected off the dual axis MEMS-fabricated scanning mirror 2204. The appropriate horizontal and vertical scanning rate signals are applied to the actuators for the mirror 2204 as required to tilt the mirror 2204 to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the light beam 2202 is reflected in the proper raster pattern, the beam 2202 is passed through a beamsplitter 2263. From the beamsplitter 2263, the light beam 2202 is passed through a focusing optical element 2264 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4. This produces a flat field of focused pixel elements on the retina. The focused pixel elements are finally projected through the cornea and onto the retina 2265 of a subject 2266 in a raster pattern. The light source 2201 in this device may consist of a single color laser or a combination of red, blue and green lasers to produce a full spectrum of colors at the focus point or a UV or IR laser for additional diagnostic purposes. The light reflected 2256 off the retina 2265 at the spot focus point is reflected in accordance with the opacity/color of the retina 2265 at the spot location. This light received from the retina 2256 is reflected off the beamsplitter 2263 and collected by a radiation detector 2254 which generates an image signal 2262 for further processing by electronics (e.g., converted into a digital signal). A color signal may be generated in one of the following manners. First, the appropriately colored laser 2201 may be scanned in sequential fashion (i.e., red, blue, green, red, blue, etc.) across the retina 2265 and the reflected laser light 2256 detected by a single, panchromatic detector 2254 in serial fashion. Or, secondly, the tricolored lasers 1 may be on at all times, scanned in a raster and three monochromatic (i.e. sensitive to red, blue and green light) detectors 2254 detect the laser light reflected from the retina 2256 in parallel

fashion. Such a device would have applications in ophthalmology and as a retinal venous pattern sensor for security purposes.

The combination specified in configuration 4 may be used in a flying spot microscope 2300. As illustrated in Figure 23, the light source 2301 for this device would be a collimated unmodulated laser. The light beam is passed through a collimating optical element 2303 and is reflected off the dual axis MEMS-fabricated scanning mirror 2304. The appropriate horizontal and vertical scanning rate signals are applied to the actuators of the mirror 2304 as required to tilt the mirror 2304 to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the light beam 2302 is reflected in the proper raster pattern, the beam 2302 is passed through a compression optical element 2367 and then through a microscope objective 2368 as in the case of configuration 4. This produces a flat field of focused pixel elements. The focused pixel elements are passed through the microscope eyepiece lens 2370, contained in a housing 2369, and finally projected onto the desired object surface 2372 (e.g., a microscope slide 2371) and scanned in a raster pattern. The light source 2301 in this device may consist of a single color laser or a combination of red, blue and green lasers to produce a full spectrum of colors at the focus point. The light transmitted through the microscope slide at the spot focus point 2372 is transmitted in accordance with the opacity/color of the microscopic object 2372 at the spot location. This transmitted (or reflected) light is collected by a radiation detector 2354 which generates an image signal 2362 for further processing by electronics (e.g., converted into a digital signal). A color signal 2362 may be generated in one of the following manners. First, the appropriately colored light beam 2302 may be scanned in sequential fashion (i.e., red, blue, green, red, blue, etc.) through the microscopic object 2372 and the transmitted laser light detected by a single, panchromatic detector 2354 in serial fashion. Or, secondly, the tricolored lasers 2301 may be on at all times, scanned in a raster and three monochromatic (i.e.

sensitive to red, blue and green light) detectors 2354 detect the laser light transmitted through the microscopic object 2372 in parallel fashion.

The combination specified in configurations 3 or 4 may be used in a flying spot endoscope or laproscope 2400. As illustrated in Figures 24A and B, the light source for this device would be a collimated unmodulated laser. The collimated light beam is passed into an optical fiber 2473 at the proximal end of an endoscope. The light travels through the fiber to a refractive optical prism which aims the beam 2402 to a reflective focusing optical element 2476 (reflective-diffractive, reflective-gradient index or conventional reflective) as in the case of configuration 3. This collimating optical element 2476 is positioned on the center of a focusing optical element 2475 which forms a cap at the distal tip of the catheter 2477. In the case of configuration 4, this optical element 2476 performs a pre-collimating function. Next, the beam 2402 is reflected off the dual axis MEMS-fabricated scanning mirror 2404. The appropriate horizontal and vertical scanning rate signals are applied to the actuators of the mirror 2404 as required to tilt the mirror 2404 to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the light beam 2402 is reflected in the proper raster pattern, the beam 2415 is passed through a focusing optical element 2475 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4. This produces a flat field of focused pixel elements. The focused pixel elements are finally projected onto the desired subject and scanned in a raster pattern. The light source 2473 in this device may consist of a single color laser or a combination of red, blue and green lasers to produce a full spectrum of colors at the focus point or a UV or IR laser for additional diagnostic purposes. Of course, the proper fibers 2473 (e.g., fluoride glass fibers for IR) must be used to conduct the desired frequency of light to the distal tip. The light reflected off the subject 2456 at the spot focus point is

reflected in accordance with the opacity/color of the subject at the spot location. This reflected light 2456 is collected by a radiation detector 2454 located at the distal tip which generates an image signal for further processing by electronics (e.g., converted into a digital signal). The video data signal is then conveyed to the proximal end of the catheter 2477 by cable 2462. The data signal is further processed by the electronics 2478 and displayed as a video image on the television monitor 2479. A color signal may be generated in one of the following manners. First, the appropriately colored light beam 2402 may be scanned in sequential fashion (i.e., red, blue, green, red, blue, etc.) across the image field and the reflected laser light 2456 detected by a single, panchromatic detector 2454 in serial fashion. Or, secondly, the tricolored light beams 2402 may be on at all times, scanned in a raster pattern and three monochromatic (i.e. sensitive to red, blue and green light) detectors 2454 detect the laser light 2456 reflected from the object in parallel fashion. This endoscope may have a remotely maneuverable distal tip in accordance with similar devices in the art (e.g., shape memory alloy/TiNi actuators). Such a device has the distinct advantage of reduced diameter for given resolution relative to other endoscopic imaging technologies (e.g., CCD micro cameras or fiber bundles). For example, the diffraction limiting pixel size (i.e., individual fiber diameter) of a fiber bundle is approximately 8 μm. Thus, a pixel field of 700 x 525 pixels (approximately the U.S. television standard) would fit into an area 7 mm in diameter (the diagonal of the pixel field). A single circular scanning mirror 1 mm in diameter will provide the same resolution. This represents an area reduction of 49 times.

The combination specified in configurations 5 and 6 may be used as a slide or cinematography television pickup device 2500. The configurations using combinations 5 and 6 are considered image dissector scanners in the art. As illustrated in Figure 25, the light source 2558 for this device would be a white light source located behind the transparent medium 2560 (slide or cine

film 2561). The white light 2515 is directed through the transparent medium 2560 to evenly illuminate the transparent medium 2560. The collected light 2556 is passed through a focusing optical element 2503 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 5. This will eventually produce a flat field of focused pixel elements. Next, the beam 2556 is reflected off the dual axis MEMS-fabricated scanning mirror 2504. The appropriate horizontal and vertical scanning rate signals are applied to the actuators for the mirror 2504 as required to tilt the mirror to generate a raster pattern 2522 at the appropriate frame and field rates using techniques well established in the art. Once the received light 2556 is reflected in the proper raster pattern 2522, the now stationary beam 2502 is passed through a focusing optical element (diffractive, reflective, gradient index refractive or conventional refractive) (not illustrated) as in the case of configuration 4 (not illustrated). This produces a curved field of focused pixel elements. The focused pixel elements are finally collected by an appropriately sensitive detector 2554. The detector 2554 converts the light signal to an electronic video signal 2562 for amplification 2559 and further signal processing. The light source 2558 in this device may consist of a white light source and a single (for monochrome) or red, green and blue sensitive detectors 2554 may be used in any of the above combinations to produce a data signal 2562. Additionally, a sequential light source 2558 of red, blue and green light in combination with a single panchromatic detector 54 or red, green and blue sensitive detectors 2554 may be used in any of the above combinations to produce a sequential color data signal 2562.

The combination specified in configuration 5 may be used in a microscope 2600. The configuration using combination 5 is considered an image dissector scanning microscope in the art. As illustrated in Figure 26, the light source 2658 for this device would be a white light source 2658 located below the microscope slide stage or above the stage to reflect light off the

microscopic object 2672. The white light is condensed and directed through the microscope slide 2671 and microscopic object 2672 to evenly illuminate the microscopic object 2672. The collected light is passed through the microscope objective 2670. The beam is then passed through the microscope eyepiece 2668 (which is supported by structure 2669) and reduced by optical element 2667 as in the case of configuration 5. This will eventually produce a flat field of focused pixel elements. Next, the beam 2656 is reflected off the dual axis MEMS-fabricated scanning mirror 2604. The appropriate horizontal and vertical scanning rate signals are applied to the scanner 2604 actuators as required to tilt the mirror to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the received light 2656 is reflected in the proper raster pattern, the now stationary beam 2656 is passed through the collimating optical element 2603 and collected by an appropriately sensitive detector 2654. The detector 2654 then generates a data signal. The light source 2658 in this device may consist of a white light source and a single (for monochrome) or red, green and blue sensitive detectors 2654 may be used in any of the above combinations to produce a data signal. Additionally, a sequential light source 2658 of red, blue and green light in combination with a single panchromatic detector 2654 or red, green and blue sensitive detectors 2654 may be used in any of the above combinations to produce a sequential color data signal.

The combination specified in configurations 5 and 6 may be used as in an endoscope or laproscope 2700. The configurations using combinations 5 and 6 are considered image dissector endoscopes in the art. As illustrated in Figures 27A and B, the light source 2758 for this device would be a white light source from a fiber bundle located at the distal tip of the endoscope. The white light 2715 is directed at the subject to evenly illuminate the subject. The reflected light 2756 is passed through a focusing optical element 2775 (diffractive,

reflective, gradient index refractive or conventional refractive) as in the case of configuration 5. This will eventually produce a flat field of focused pixel elements. Next the beam 2756 is reflected off the dual axis MEMS-fabricated scanning mirror 2704. The appropriate horizontal and vertical scanning rate signals are applied to the actuators for the mirror 2704 as required to tilt the mirror 2704 to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the received light 2756 is reflected in the proper raster pattern, the now stationary beam 2780 is reflected off a focusing optical element 2776 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4. This configuration would produce a curved field of focused pixel elements but in this case, since optical element 2775 is in the system, optical element 2776 acts as a collimating element. The focused beam 2780 is finally collected by an appropriately sensitive detector 2754. The detector 2754 generates an electrical signal that is amplified by preamplifier 2781. The video data signal is then conveyed to the proximal end of the catheter 2777 by cable 2762. The data signal is further processed by the electronics 2778 and displayed as a video image on the television monitor 2779. The light source 2758 in this device may consist of a white light source and a single (for monochrome) or red, green and blue sensitive detectors 2754 may be used in any of the above combinations to produce a data signal. Additionally, a sequential light source 2758 of red, blue and green light in combination with a single panchromatic detector 2754 or red, green and blue sensitive detectors 2754 may be used in any of the above combinations to produce a sequential color data signal. This endoscope may have a remotely maneuverable distal tip in accordance with similar devices in the art (e.g., shape memory alloy/TiNi actuators).

The combination specified in configuration 5 may be used in a telescope 2800. The configuration using combination 5 is considered an image dissector telescope in the art. As

illustrated in Figure 28, the subject 2885 to be imaged is at some great distance from the telescope objective 2884 (supported by structure 2883). The incoming light is directed through or reflected off the telescope objective (reflective or refractive telescope) as in the case of configuration 5. This will eventually produce a flat field of focused pixel elements. Next, the beam is directed through the eyepiece 2882, collimated by an optical system 2803 and reflected off the dual axis MEMS-fabricated scanning mirror 2804. The appropriate horizontal and vertical scanning rate signals are applied to the scanner 2804 actuators as required to tilt the mirror to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the received light 2880 is reflected in the proper raster pattern, the now stationary beam 2880 is collected by an appropriately sensitive detector 2854. The detector 2854 generates a data signal 2862 corresponding to the scanned image. This signal is amplified 2859 and processed for the appropriate destination (e.g., a television monitor or video recorder). A single (for monochrome) or a combination of multispectral (for color) sensitive detectors 2854 may be used in any of the above combinations to produce a color video data signal.

The combination specified in configurations 5 or 6 may be used in a horizon scanner 2900. As illustrated in Figure 29, the limb of a planet 2987 emits IR radiation 2988 while deep space emits no IR radiation. The incoming IR radiation 2988 is passed through a focusing optical element 2989 (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 5. This will eventually produce a flat field of focused pixel elements. Next, the beam is reflected off the dual axis MEMS-fabricated scanning mirror 2904. The appropriate horizontal and vertical scanning rate signals are applied to the actuators of the mirror 2904 actuators as required to tilt the mirror to generate a raster pattern at the appropriate frame and field rates using techniques well established in the art. Once the received light

2988 is reflected in the proper raster pattern, the now stationary beam 2980 is passed through a focusing optical element (not illustrated) (diffractive, reflective, gradient index refractive or conventional refractive) as in the case of configuration 4 (not illustrated). This configuration would produce a curved field of focused pixel elements. The focused beam 2980 is finally collected by an appropriately sensitive IR radiation detector 54 which generates a data signal 2962 that is amplified and processed by 2986. This device has particular application as a horizon location sensor for spacecraft guidance systems when the spacecraft is in an arbitrary attitude in reference to the planet horizon.

While the foregoing is a detailed description of the preferred embodiment of the invention, there are many alternative embodiments of the invention that would occur to those skilled in the art and which are within the scope of the present invention. Accordingly, the present invention is to be determined by the following claims.

Claims

1. A scanner, comprising:

a mirror adapted to reflect light received from a predetermined receive direction, the orientation of the mirror being controllable in two dimensions in response to control signals; and

an optical element for optical transformation of the light.

2. The scanner of claim 1 wherein the optical element optically transforms the light before the light is reflected by the mirror.

3. The scanner of claim 1 wherein the optical element optically transforms the light after the light is reflected by the mirror.

4. The scanner of claim 1 wherein the mirror receives the light from one predetermined receive direction and reflects the light in a plurality of reflected directions.

5. The scanner of claim 1 wherein the mirror receives the light from a plurality of predetermined receive directions and reflects the light in a predetermined reflected direction.

6. The scanner of claim 1 wherein the mirror receives the light from a plurality of predetermined receive directions and reflects the light in a plurality of reflected directions.

7. An image scanner, comprising:

a mirror adapted to reflect light received from a predetermined receive direction, the orientation of the mirror being controllable in two dimensions in response to control signals;

an optical element for optical transformation of the light; and

a control circuit for producing the control signals.

8. The scanner of claim 7 wherein the optical element optically transforms the light before the light is reflected by the mirror.

9. The scanner of claim 7 wherein the optical element optically transforms the light after the light is reflected by the mirror.

10. An image scanner, comprising:

a plurality of scanners, each scanner including:

a mirror adapted to reflect light received from a predetermined receive direction, the orientation of the mirror being controllable in two dimensions in response to control signals, and

an optical element for optical transformation of the light; and

a control circuit for producing control signals for each scanner in the plurality of scanners.

11. The image scanner of claim 10 wherein the optical element in each scanner in the plurality of scanners optically transforms the light before the light is reflected by the mirror in the respective scanner.

12. The image scanner of claim 10 wherein the optical element in each scanner in the plurality of scanners optically transforms the light after the light is reflected by the mirror in the respective scanner.

13. A method for scanning light in a predetermined pattern, comprising the steps of:

a) placing a mirror at a position to receive the light from a predetermined direction;

b) connecting a control circuit to the mirror, the control circuit being responsive to a control signal;

c) producing a control signal containing information representing the predetermined pattern;

d) transmitting the control signal to the control circuit, thereby controlling the orientation of the mirror in response to the control signals; and

e) optically transforming the light.

14. The method of claim 13 wherein step e) further includes optically transforming the light before the light is reflected by the mirror.

15. The method of claim 13 wherein step e) further includes optically transforming the light after the light is reflected by the mirror.

16. A scanner, comprising:

means for reflecting light received from a predetermined receive direction, the orientation of the means for reflecting light being controllable in two dimensions in response to control signals; and

means for optically transforming the light.

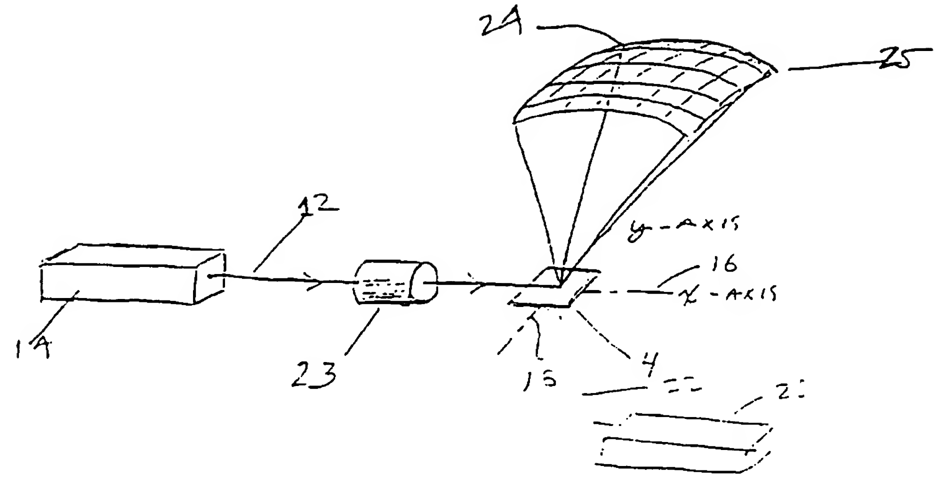
17. The scanner of claim 16 wherein the means for optically transforming the light optically transforms the light before the light is reflected by the means for reflecting light.

18. The scanner of claim 16 wherein the means for optically transforming the light optically transforms the light after the light is reflected by the means for reflecting light.

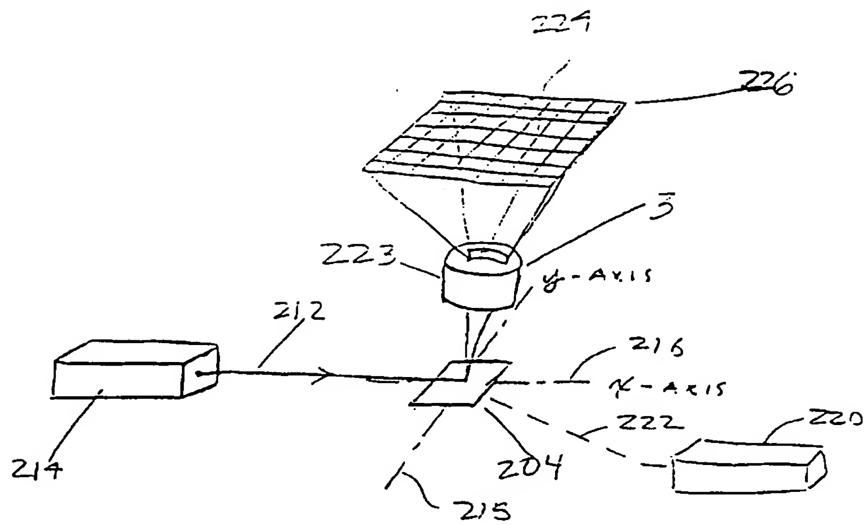
19. The scanner of claim 16 wherein the means for reflecting light receives the light from one predetermined receive direction and reflects the light in a plurality of reflected directions.

20. The scanner of claim 16 wherein the means for reflecting light receives the light from a plurality of predetermined receive directions and reflects the light in a predetermined reflected direction.

21. The scanner of claim 16 wherein the means for reflecting light receives the light from a plurality of predetermined receive directions and reflects the light in a plurality of reflected directions.



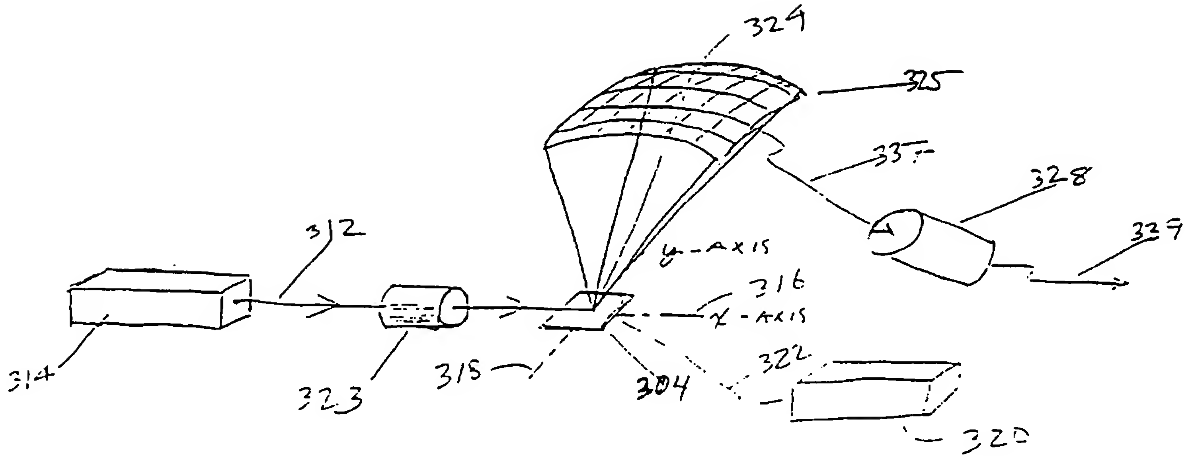
FIGURE



CONFIGURATION 2

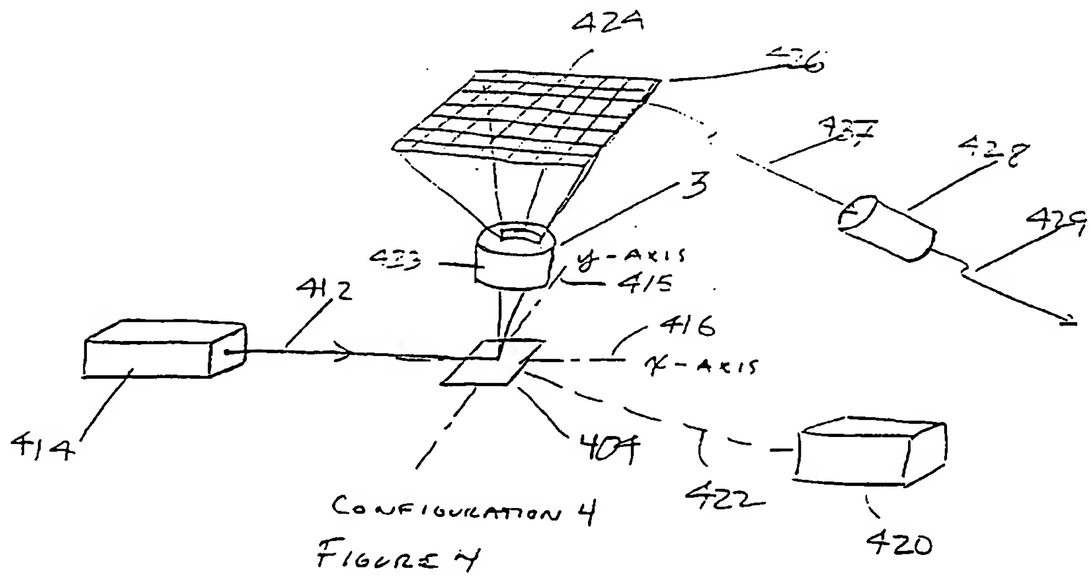
FIGURE 2

2/26



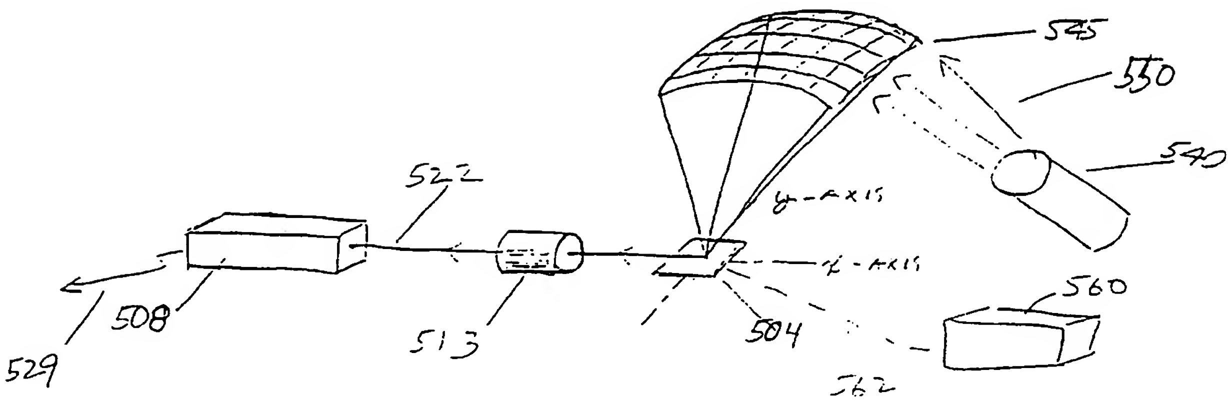
CONFIGURATION 3

FIGURE 3



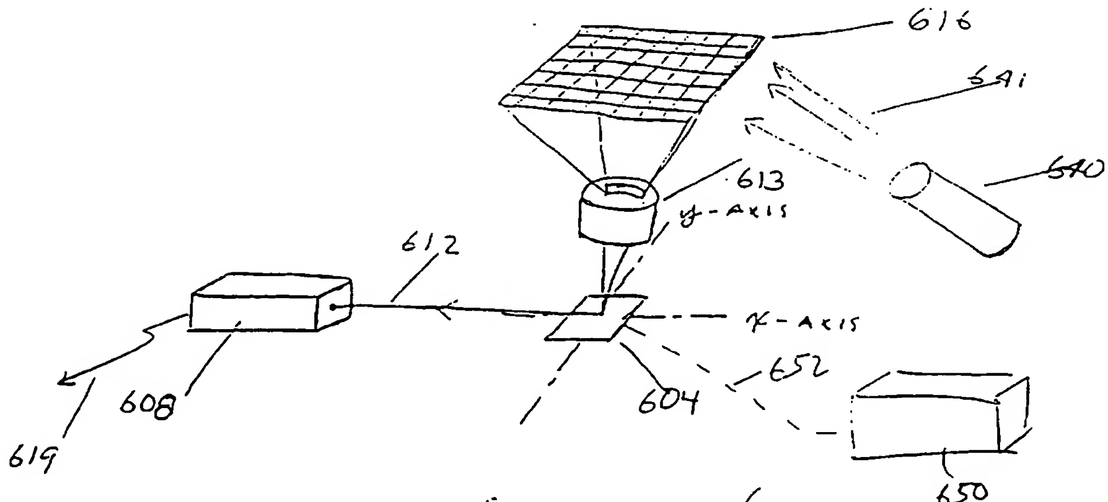
CONFIGURATION 4

FIGURE 4



CONFIGURATION 5

FIGURE 5



CONFIGURATION 6

FIGURE 6

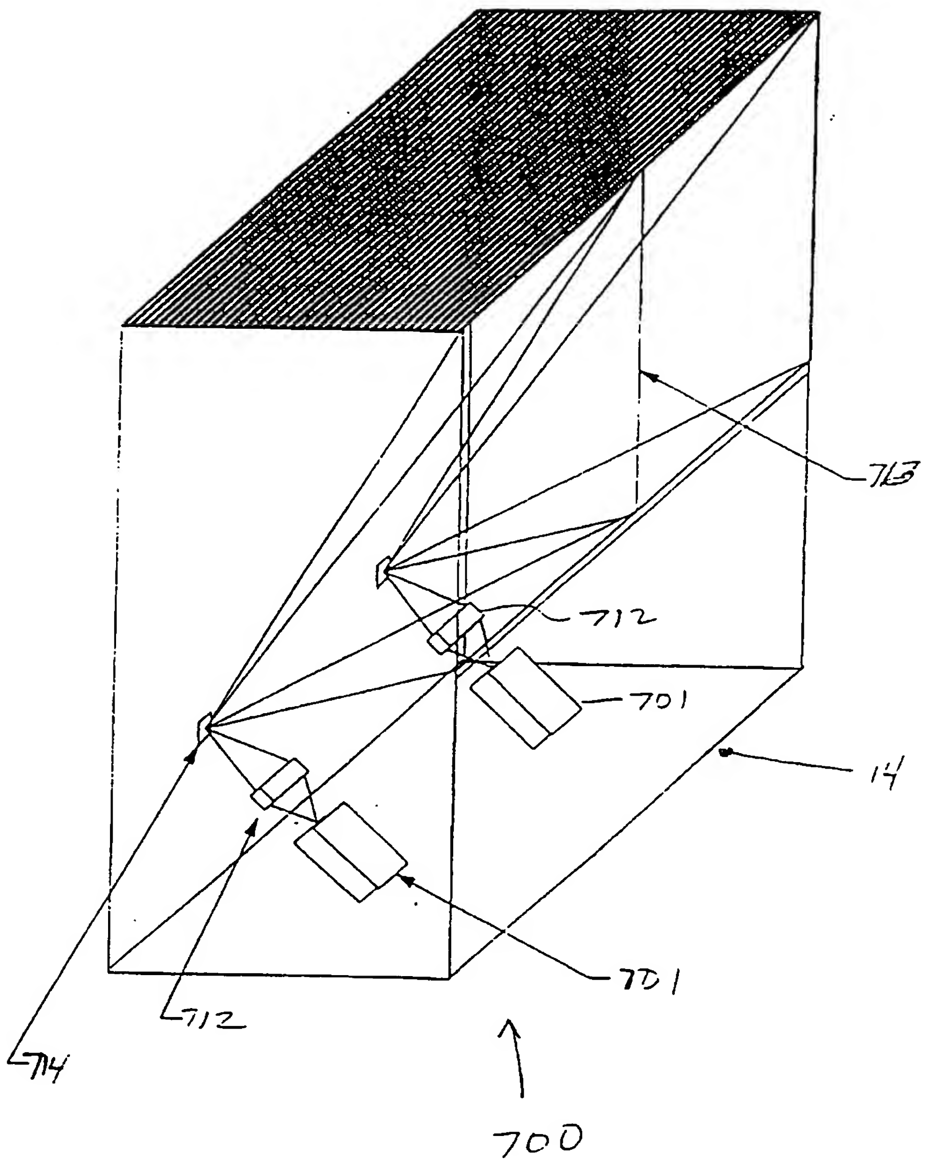
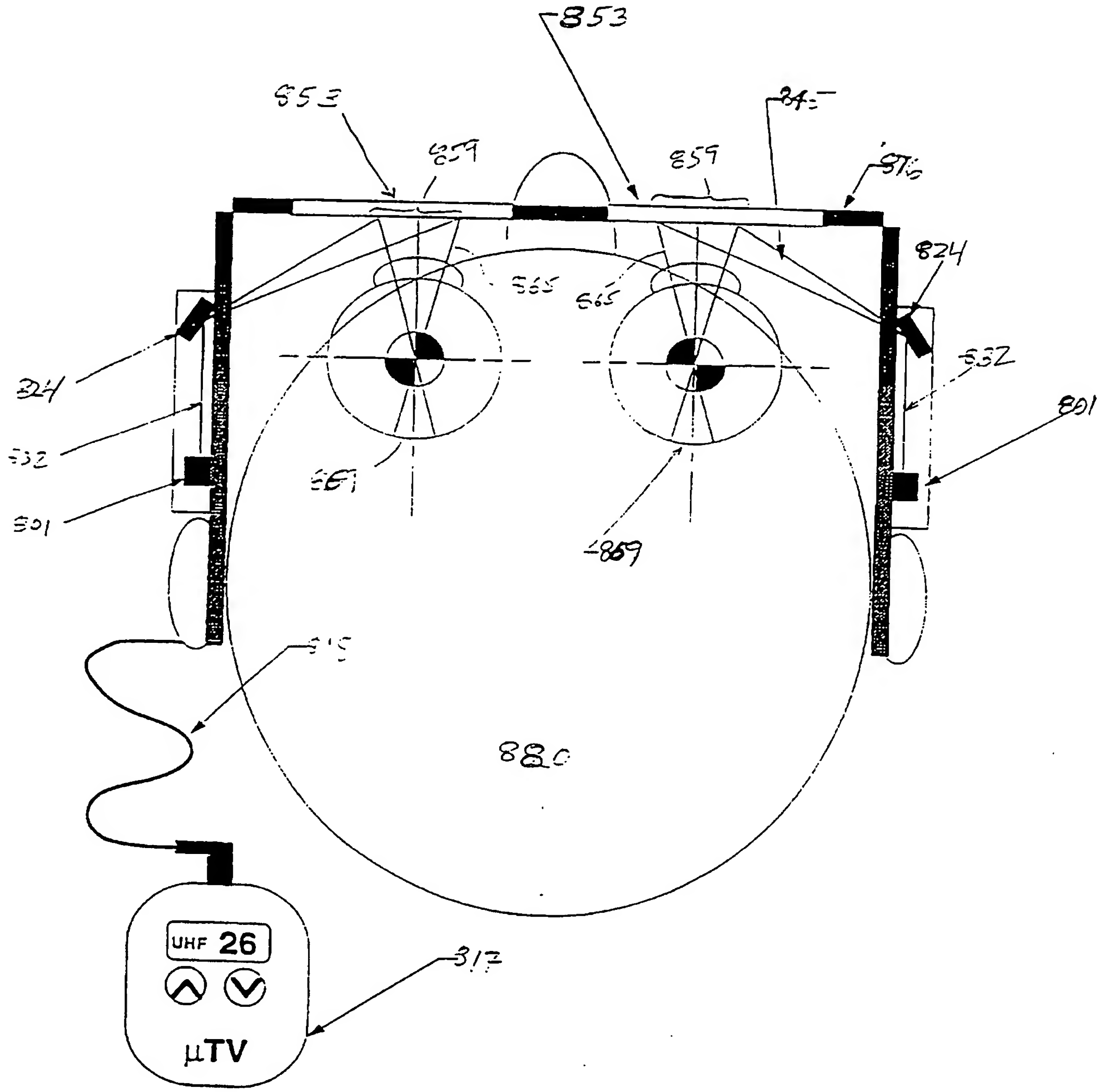


FIGURE 7

5/26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853
859
859
845
876
824
865
865
824
832
832
801
801
867
869
815
880
UHF 26
µTV
817

Figure 8

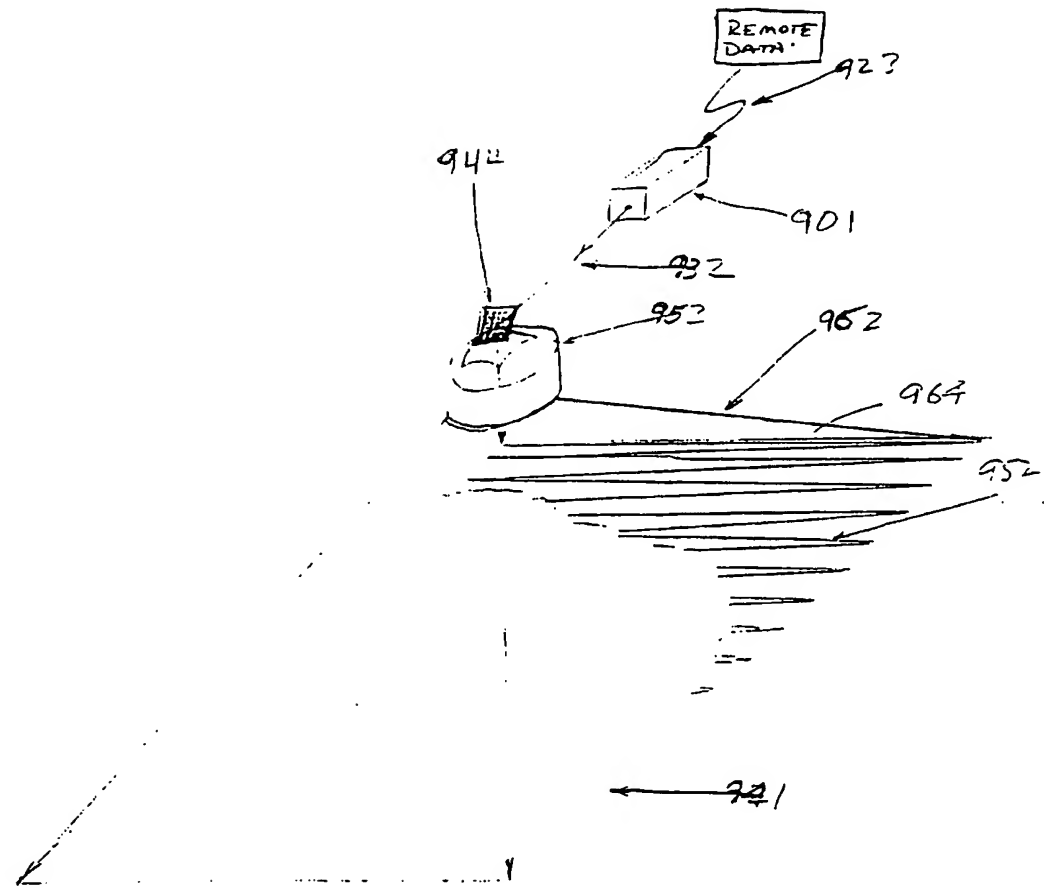


FIGURE 9

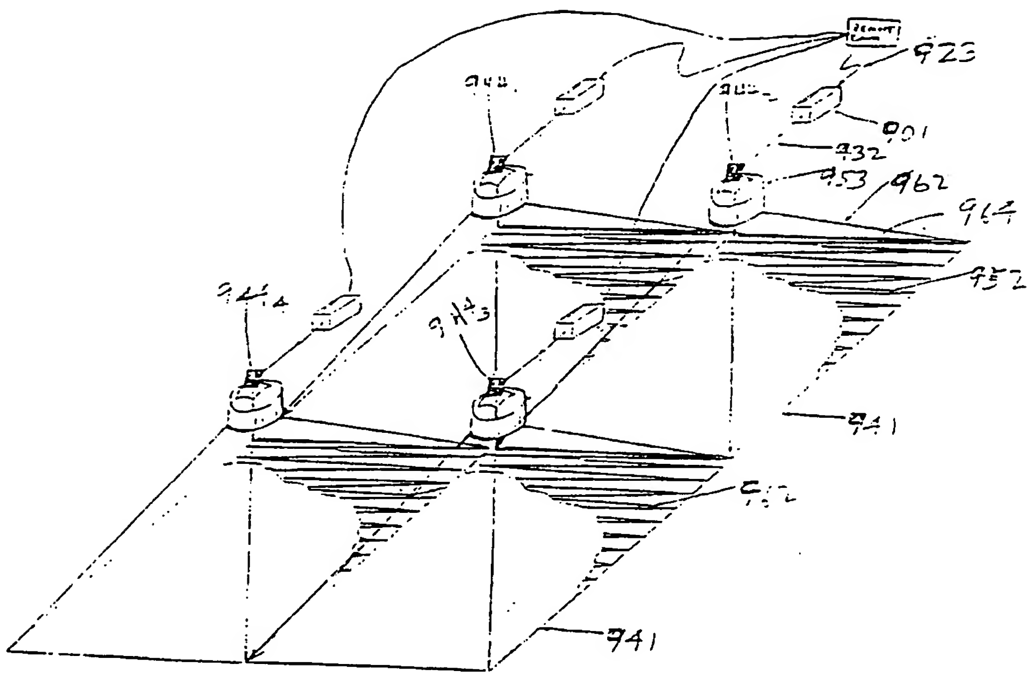


FIGURE 10

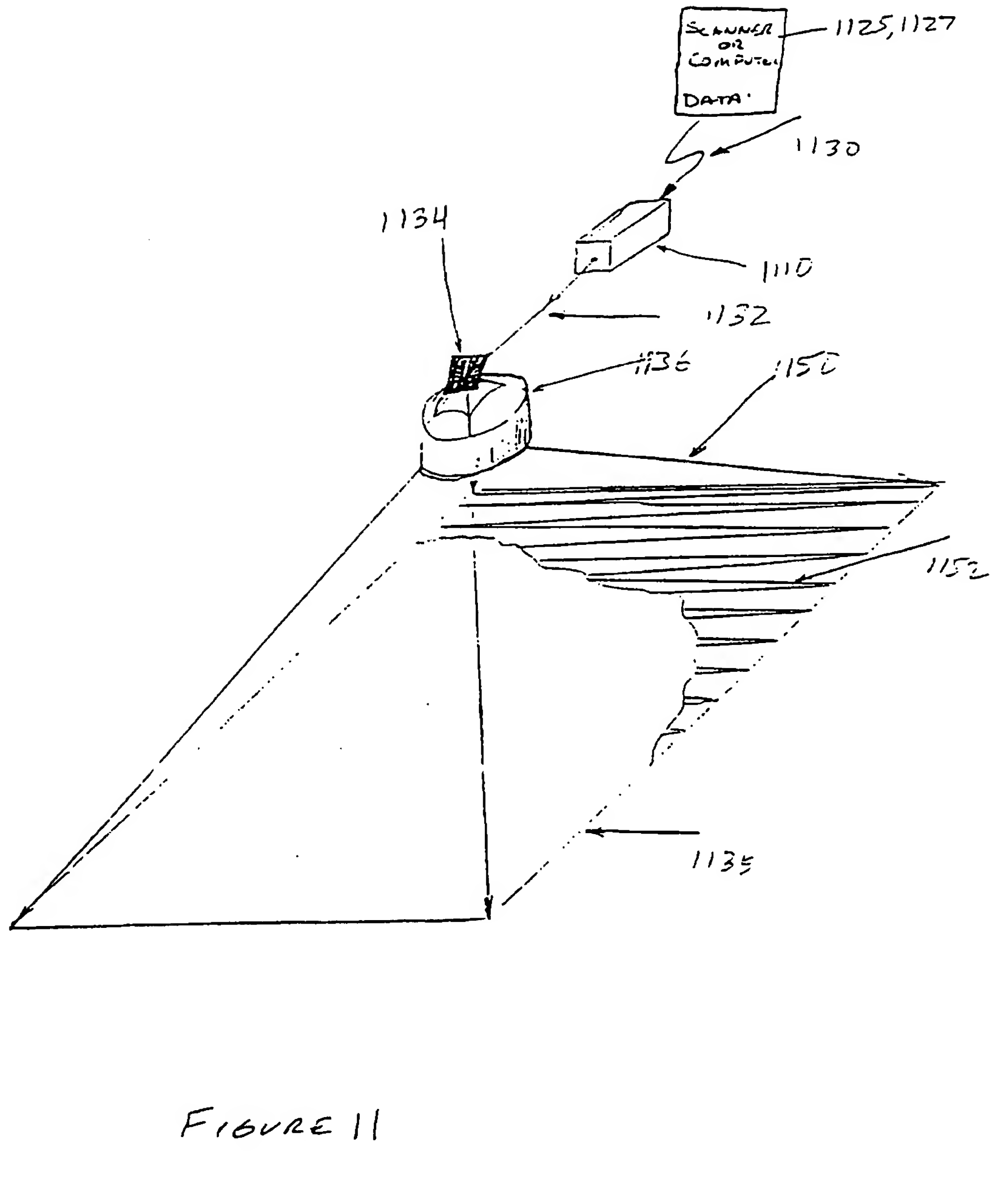

SCANNER OR COMPUTER
DATA
1125,1127
1130
1134
1110
1132
1136
1150
1152
1135

FIGURE 11

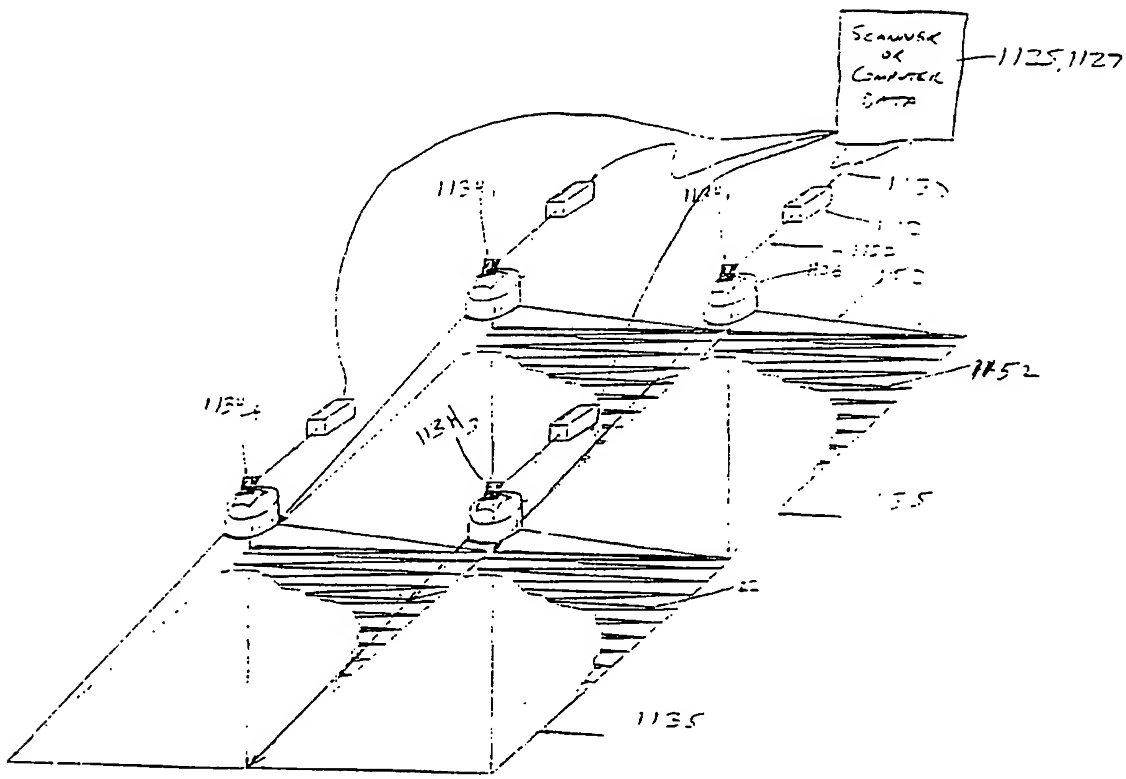
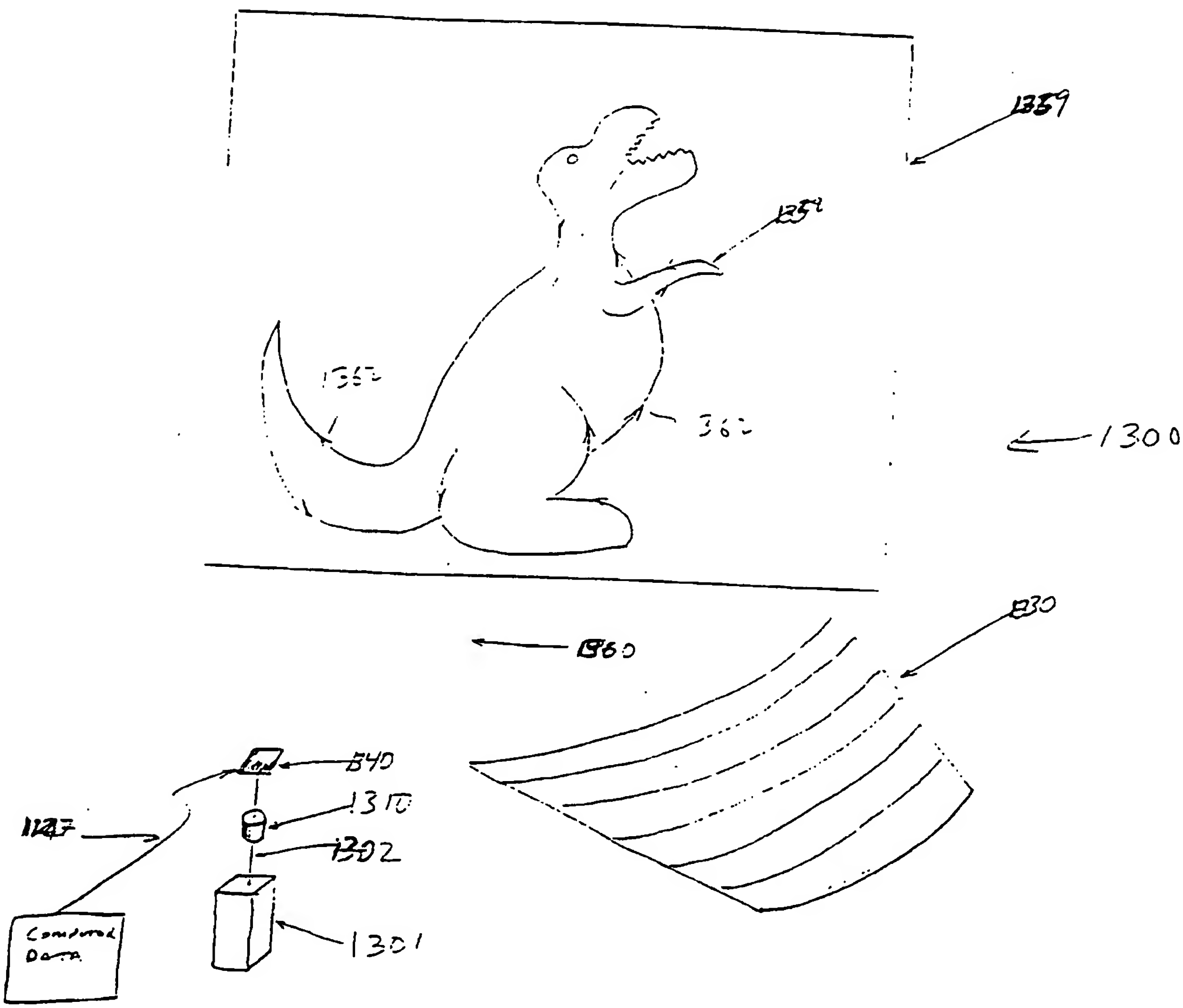


FIGURE 12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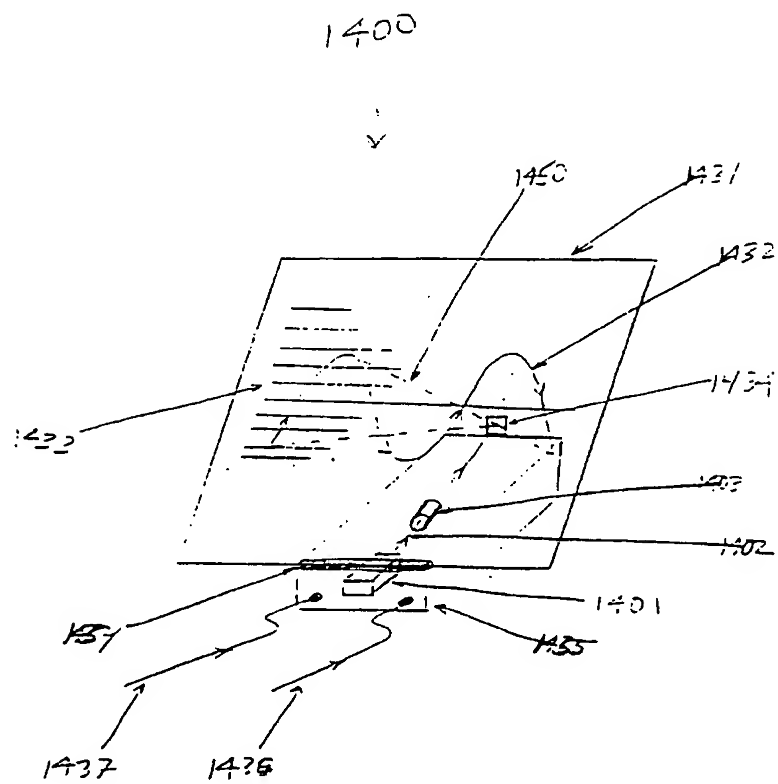
1352
1362
1362
1300
1360
1330
840
1310
1302
1127
Computer Data
1301

FIGURE 13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1450
1431
1432
1434
1433
1403
1402
1401
1434
1435
1437
1436

FIGURE 14

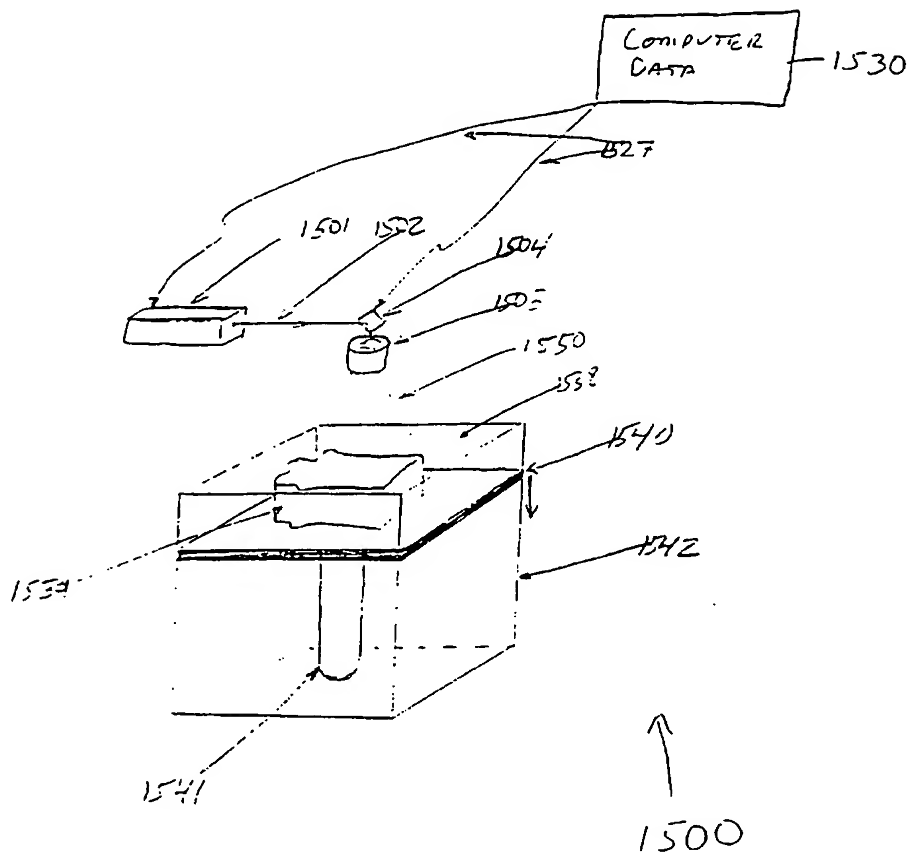
COMPUTER DATA
1530
1527
1501
1502
1504
1505
1550
1533
1540
1542
1539
1541
1500

FIGURE 15

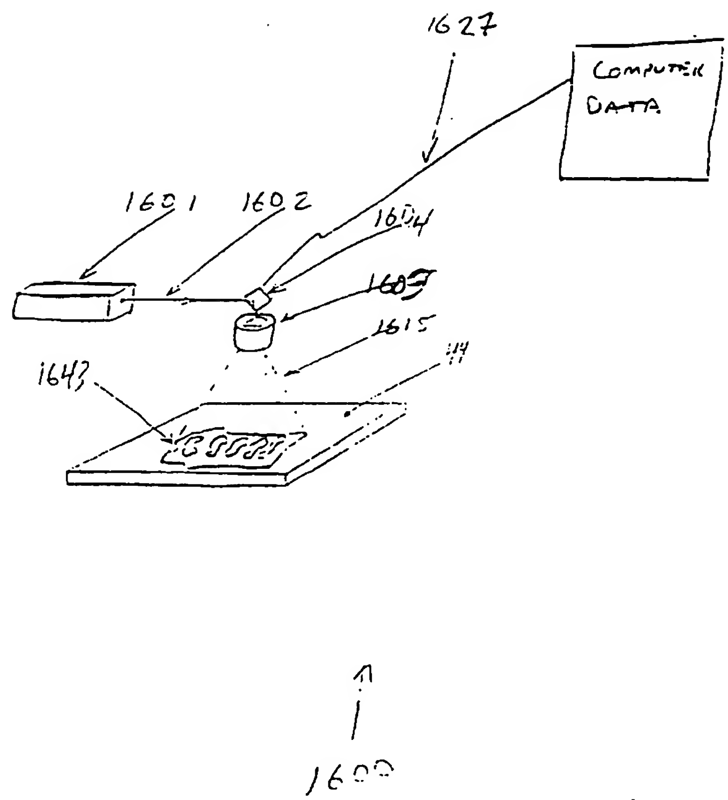

FIGURE 16

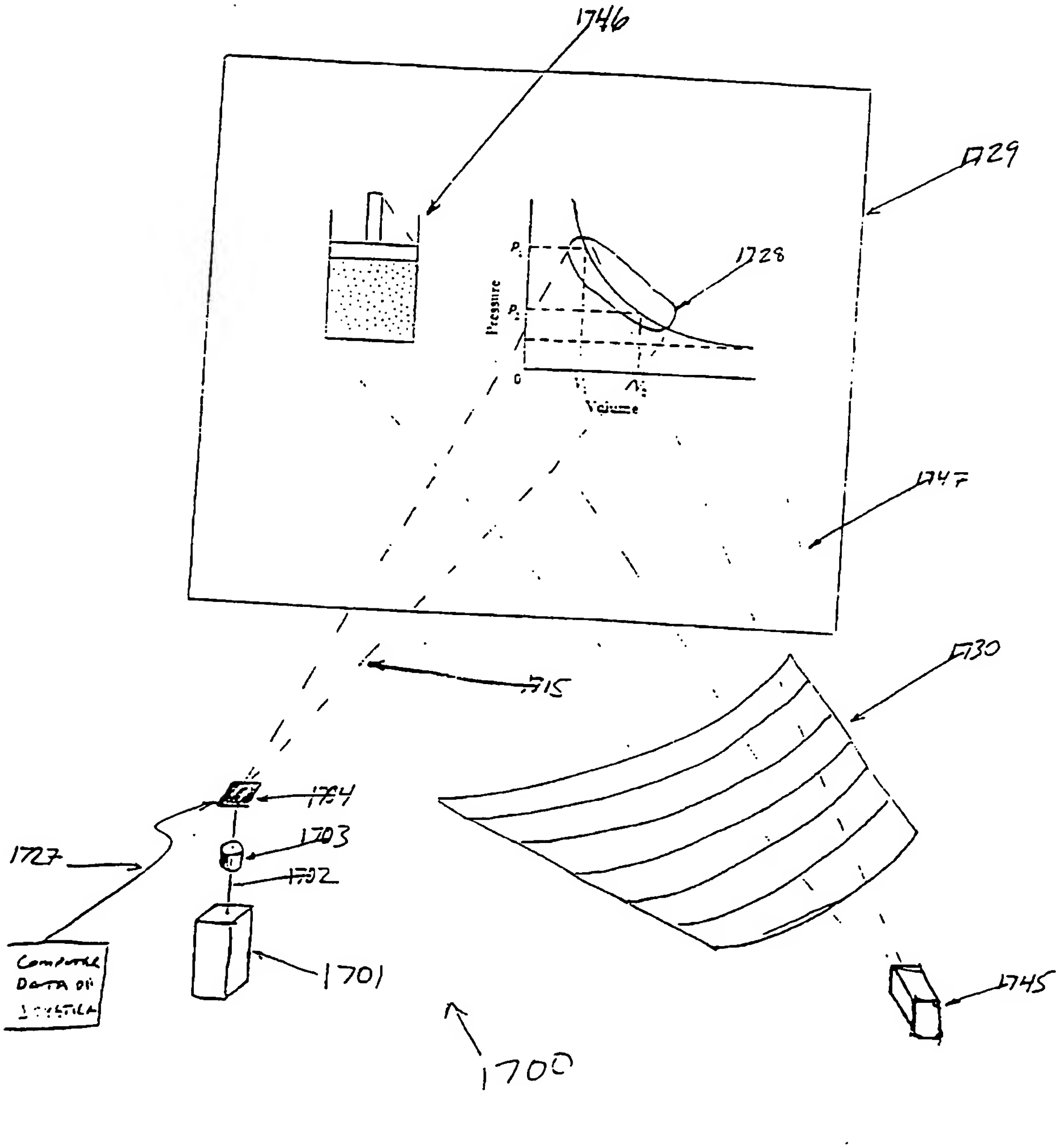
1746
1729
1728
Pressure
Volume
1747
1730
1715
1704
1703
1702
1727
1701
1745
1700
Computer Data or Systems

FIGURE 17

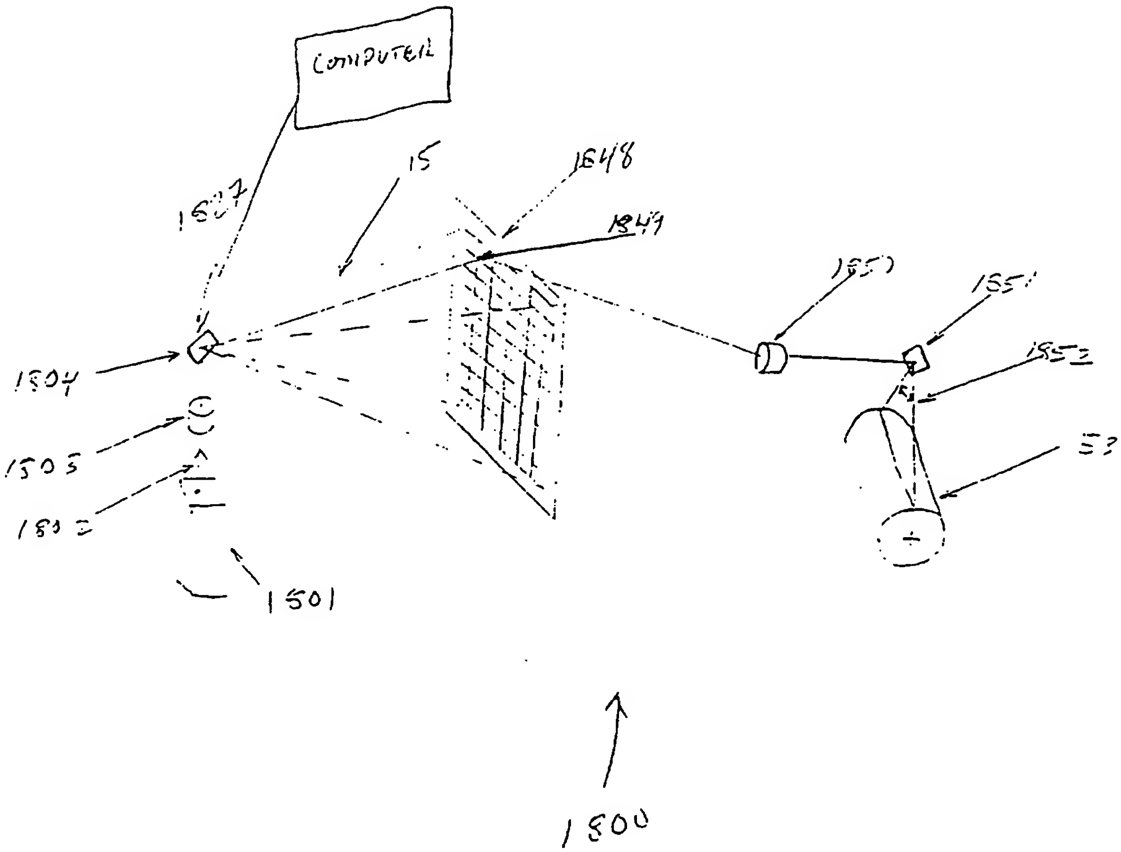
COMPUTER
1507
15
1848
1849
1850
1851
1852
1504
1505
1802
1501
1800

FIGURE 18

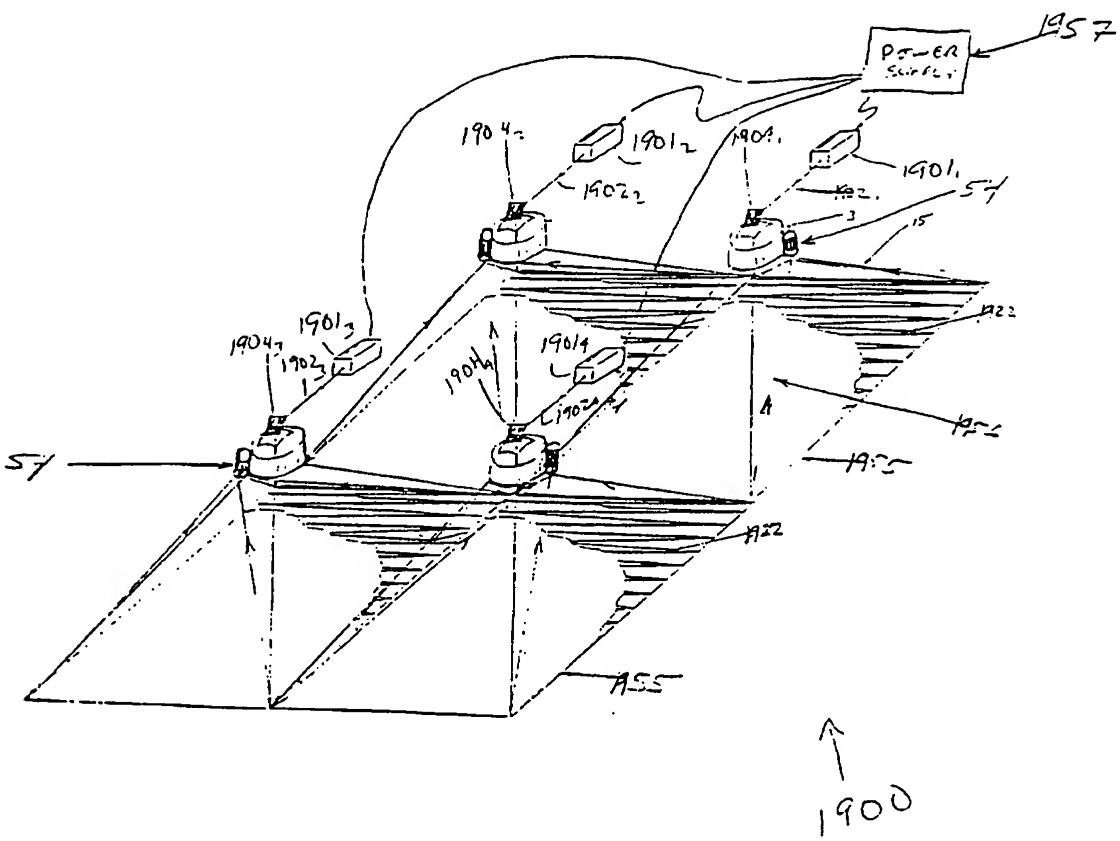

FIGURE 19

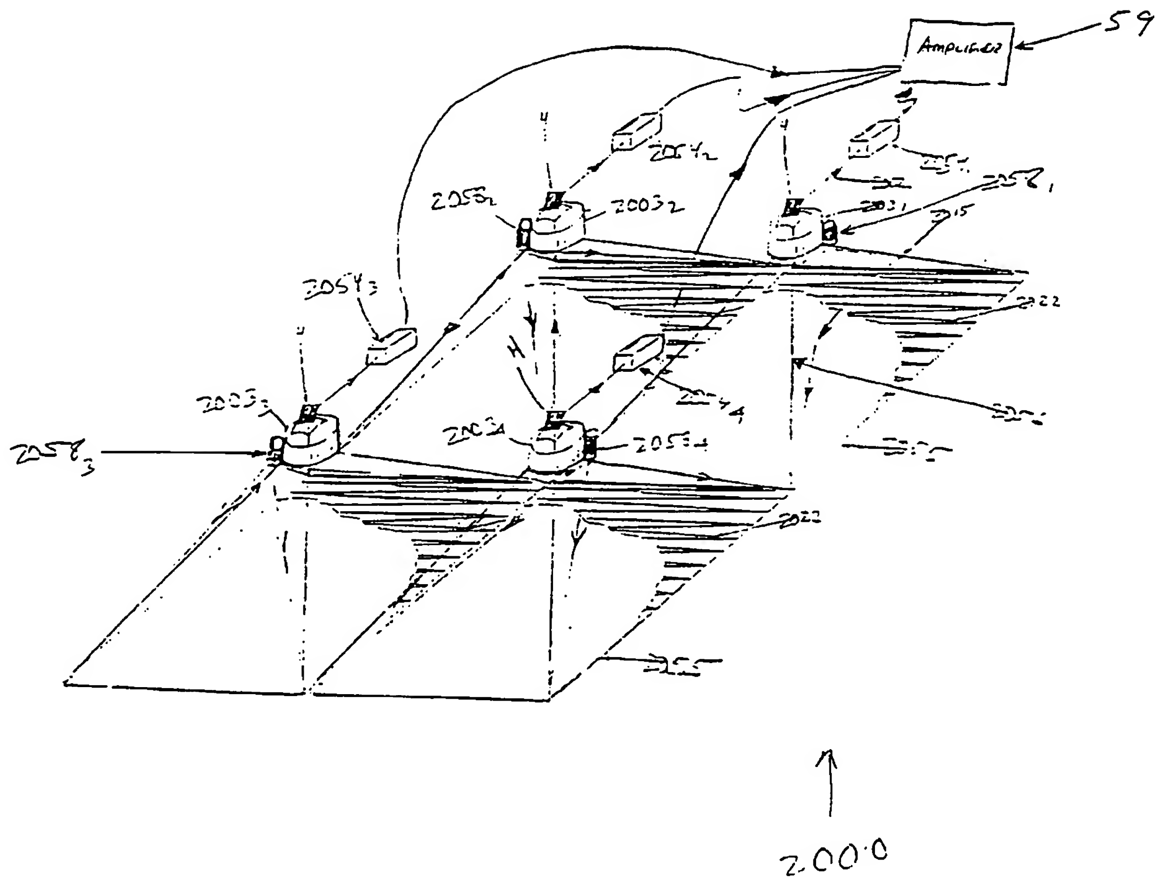

FIGURE 20

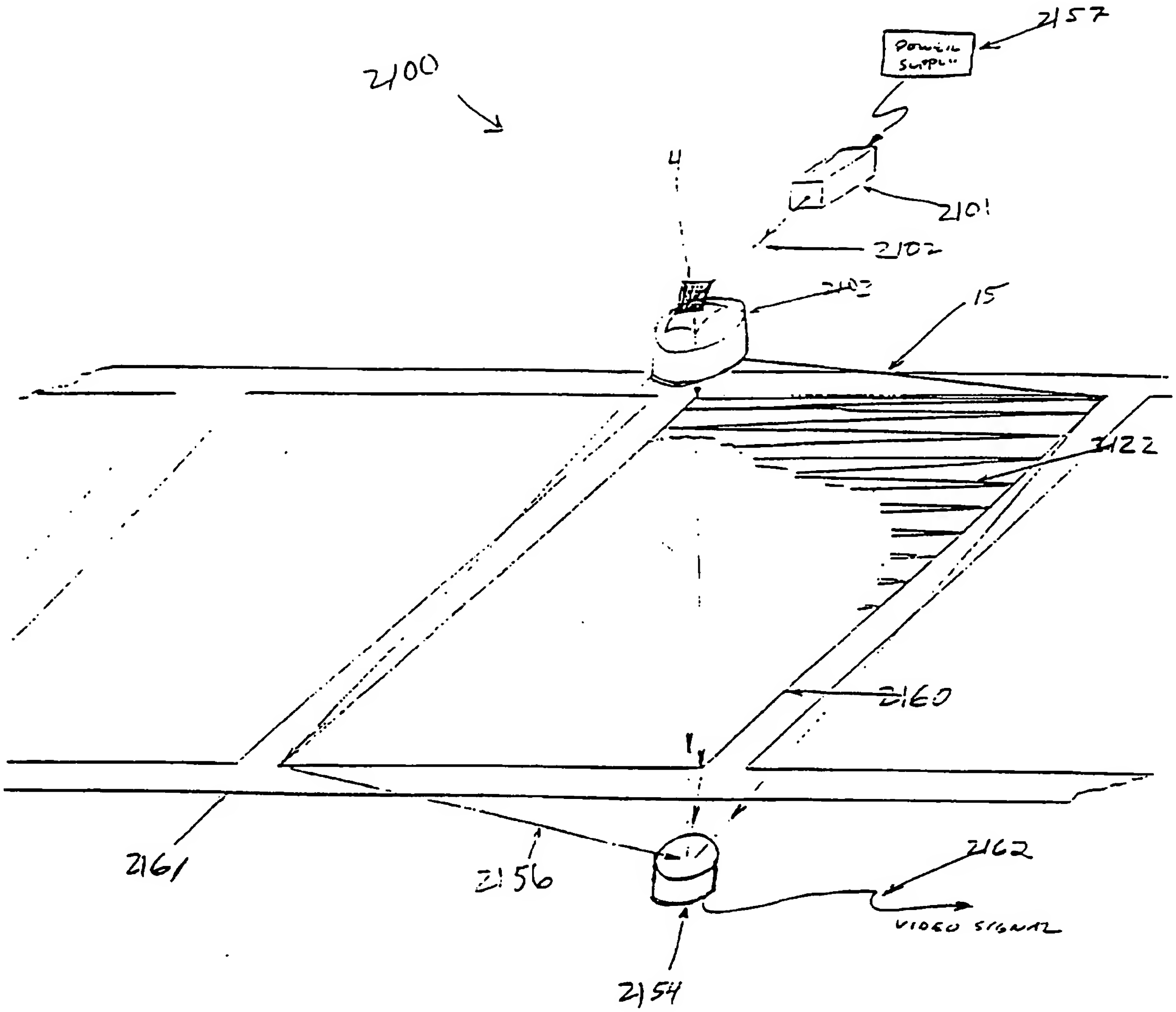
2100
2157
POWER SUPPLY
4
2101
2102
2103
15
2122
2160
2161
2156
2162
VIDEO SIGNAL
2154

FIGURE 21

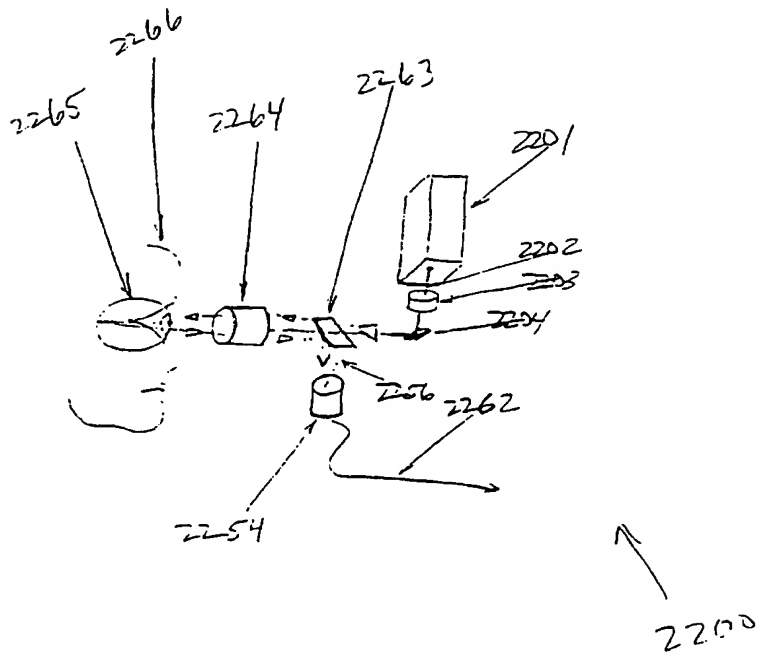

FIGURE 22

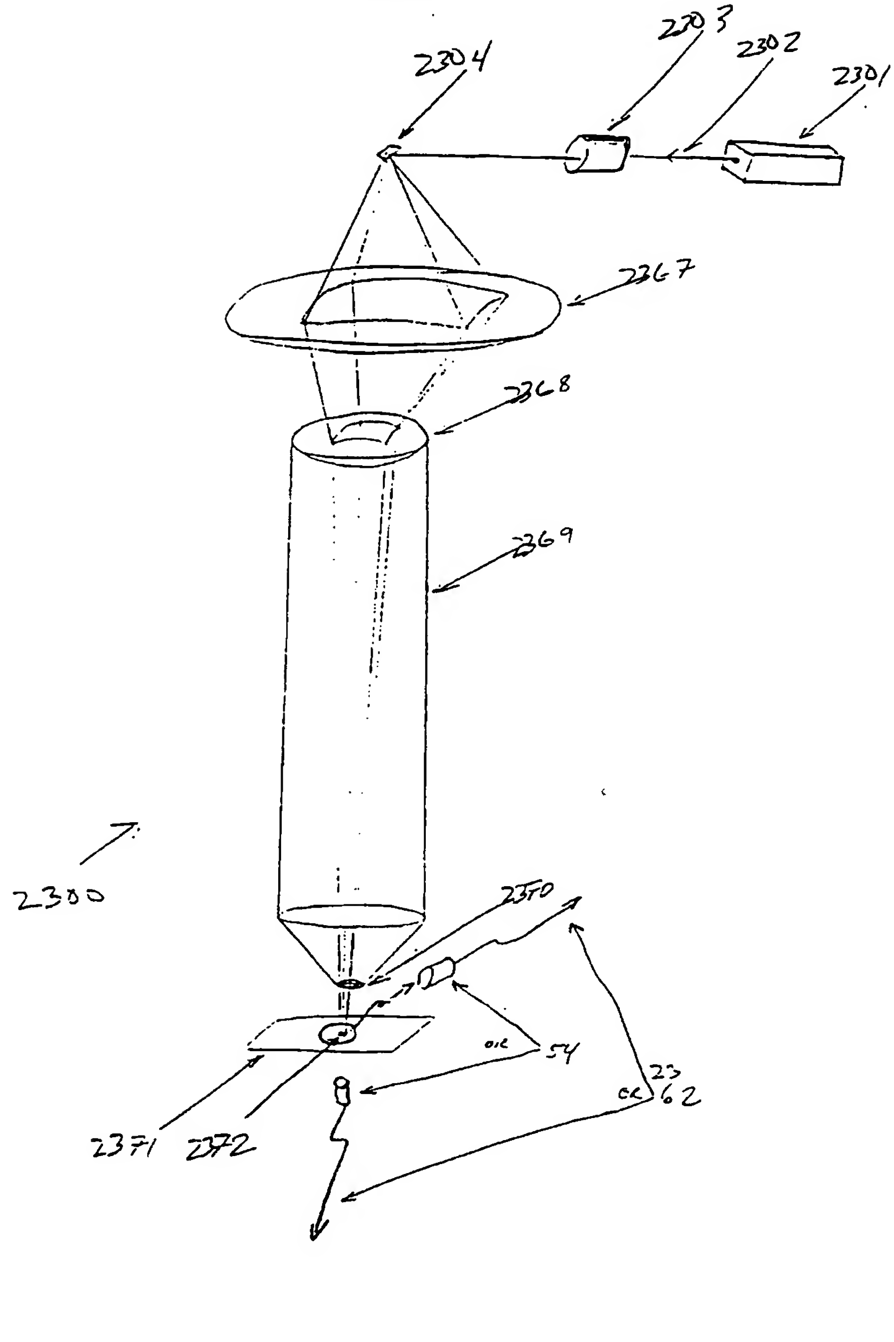
2304
2303
2302
2301
2367
2368
2369
2300
2370
54
or
23
62
or
2371
2372

Figure 23

FIG. 24A

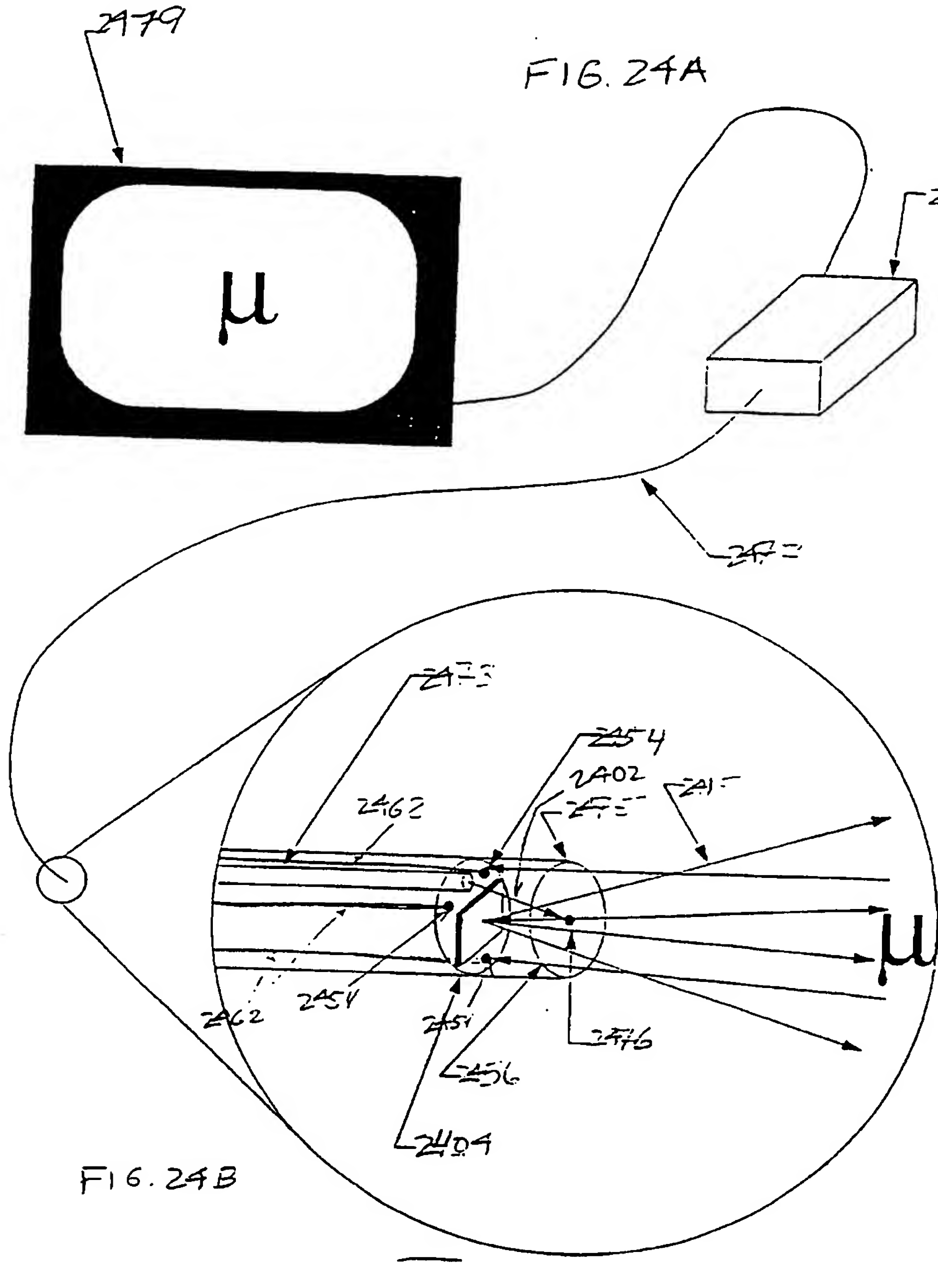

FIG. 24B

etail

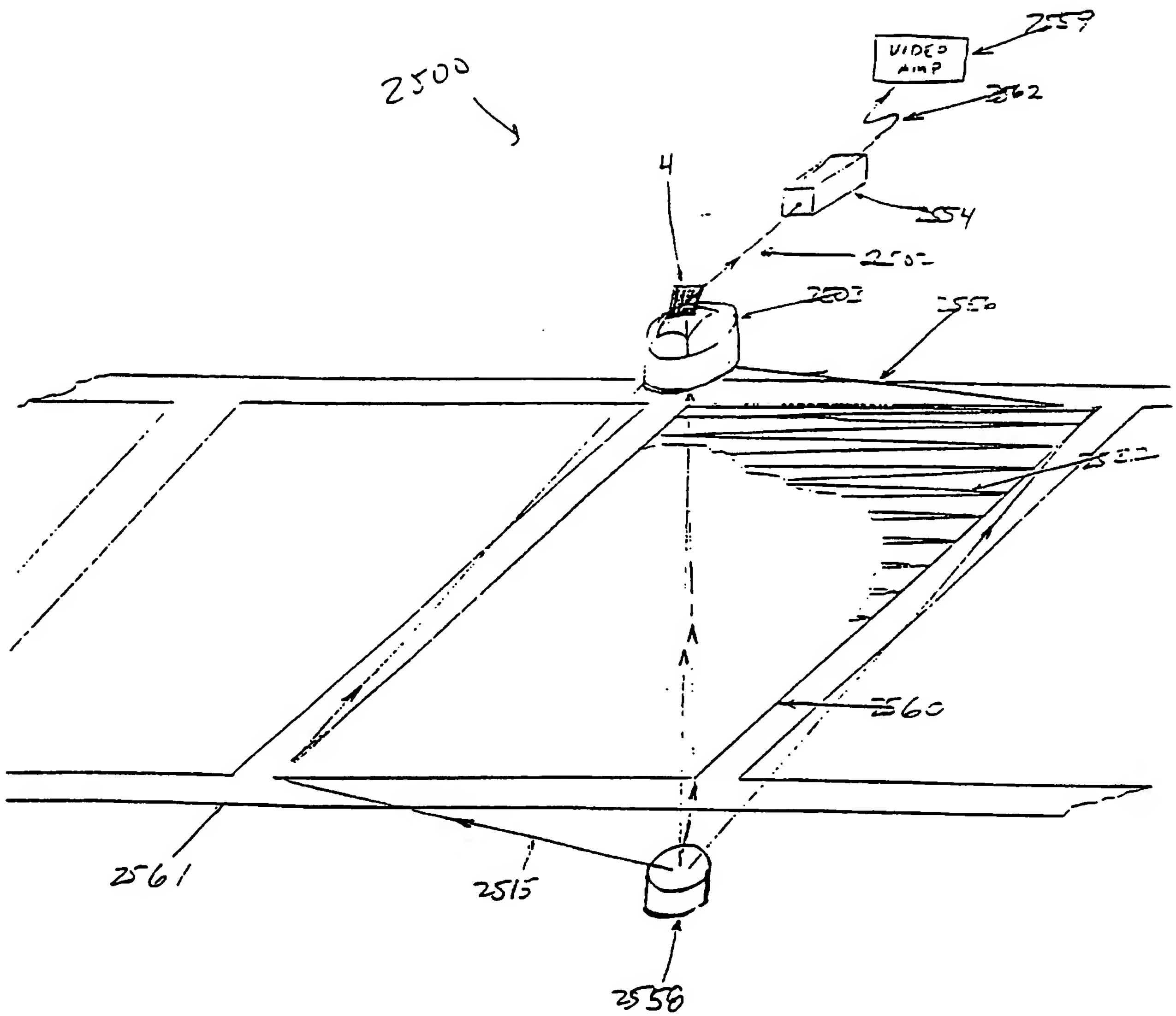

FIGURE 25

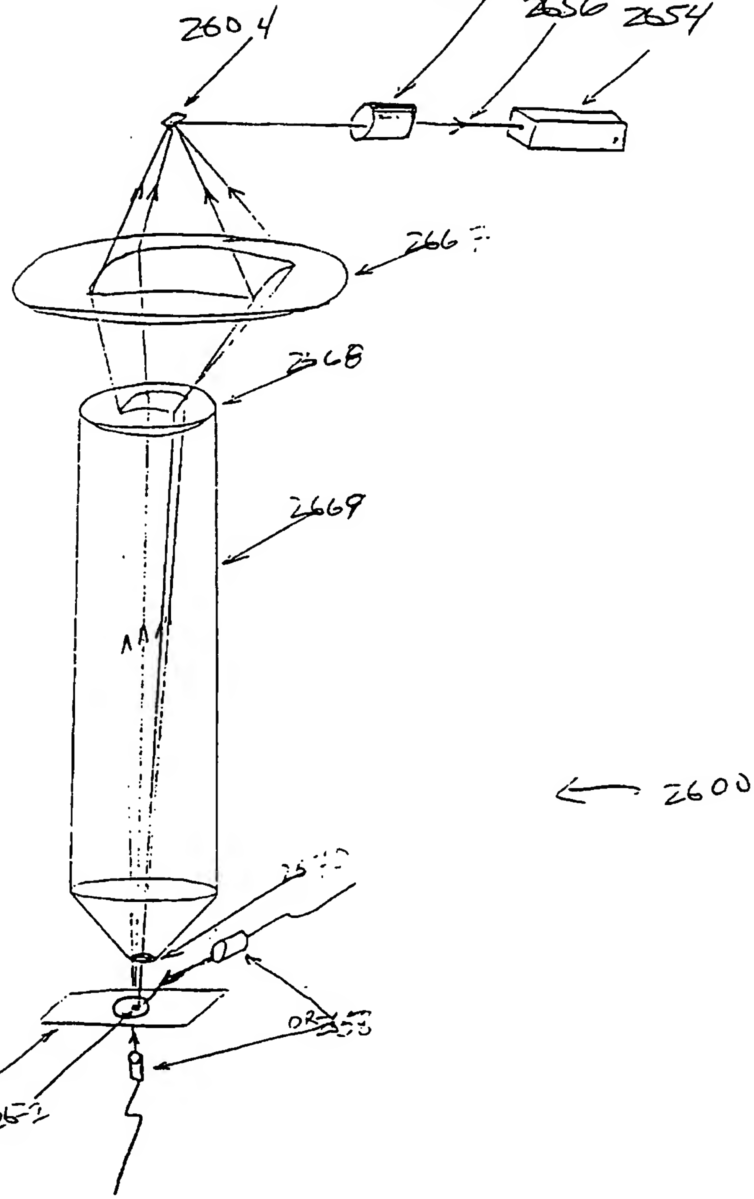

Figure 26

FIG. 27A

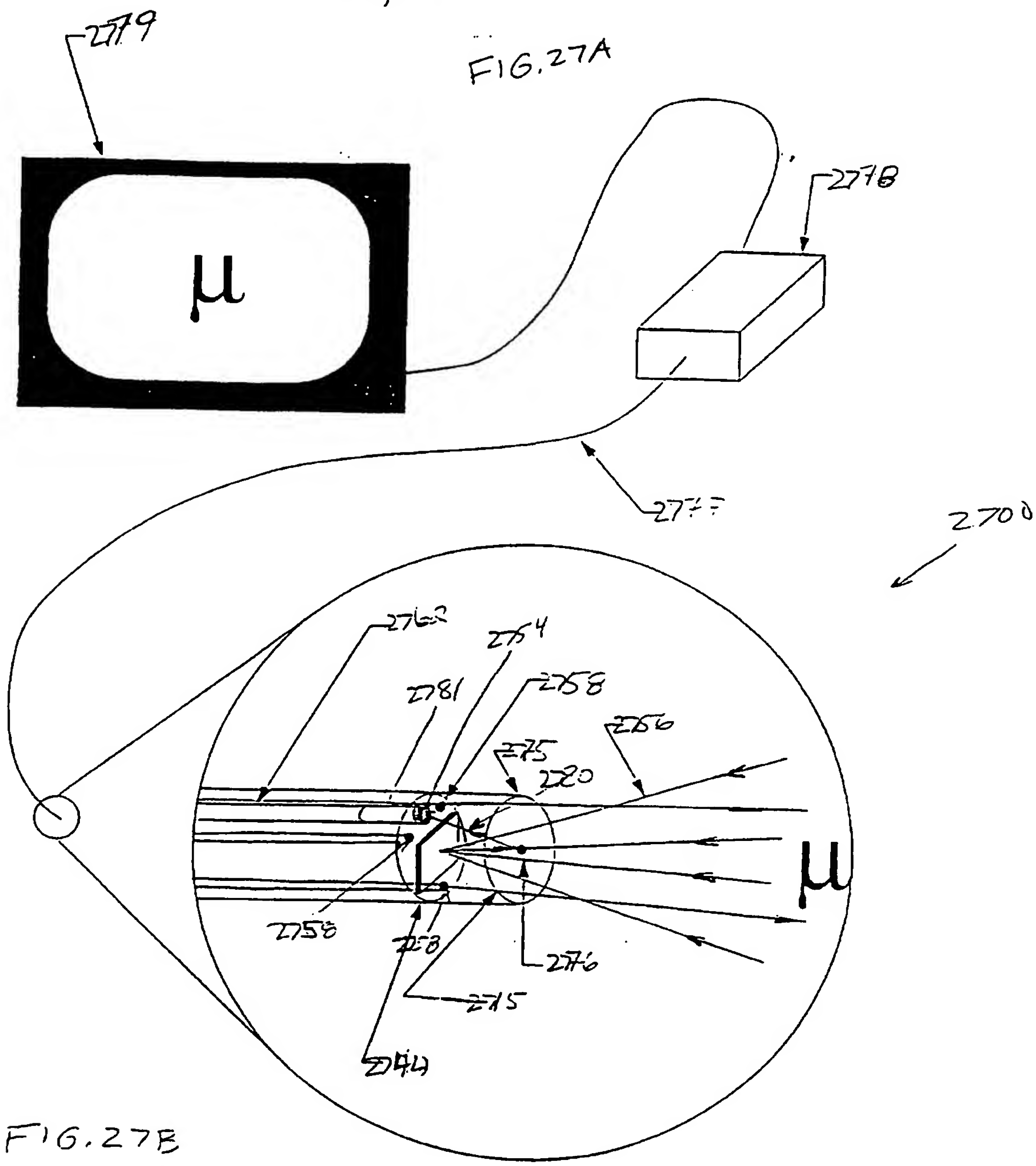

FIG. 27B

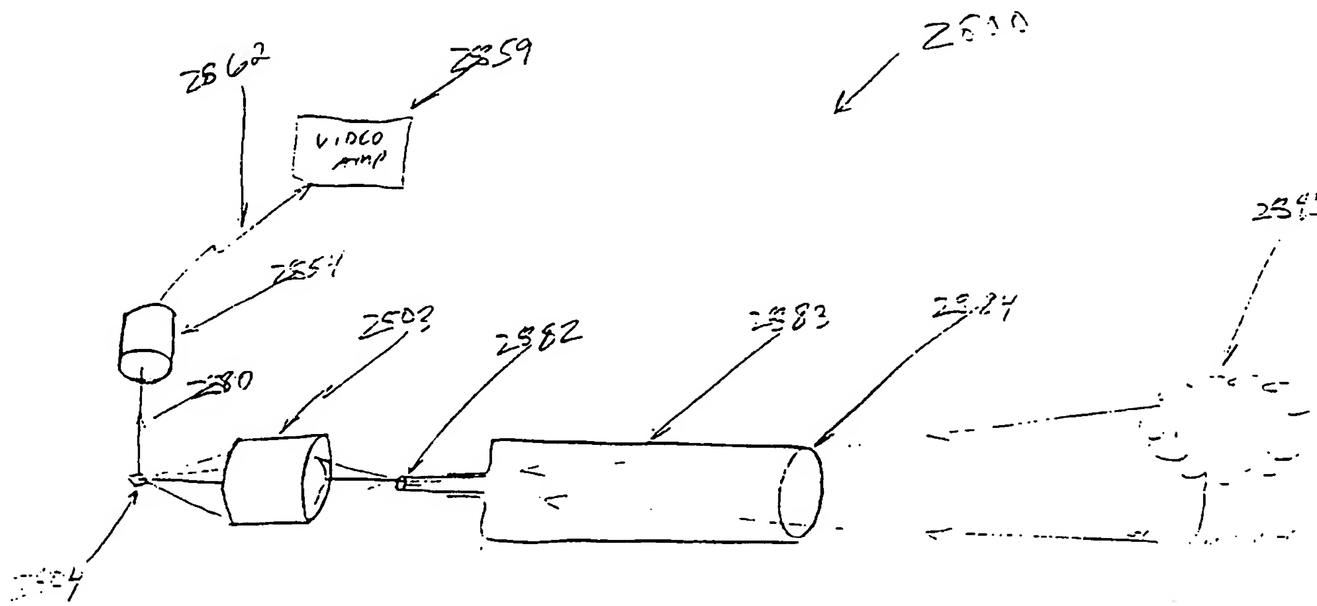

FIGURE 28

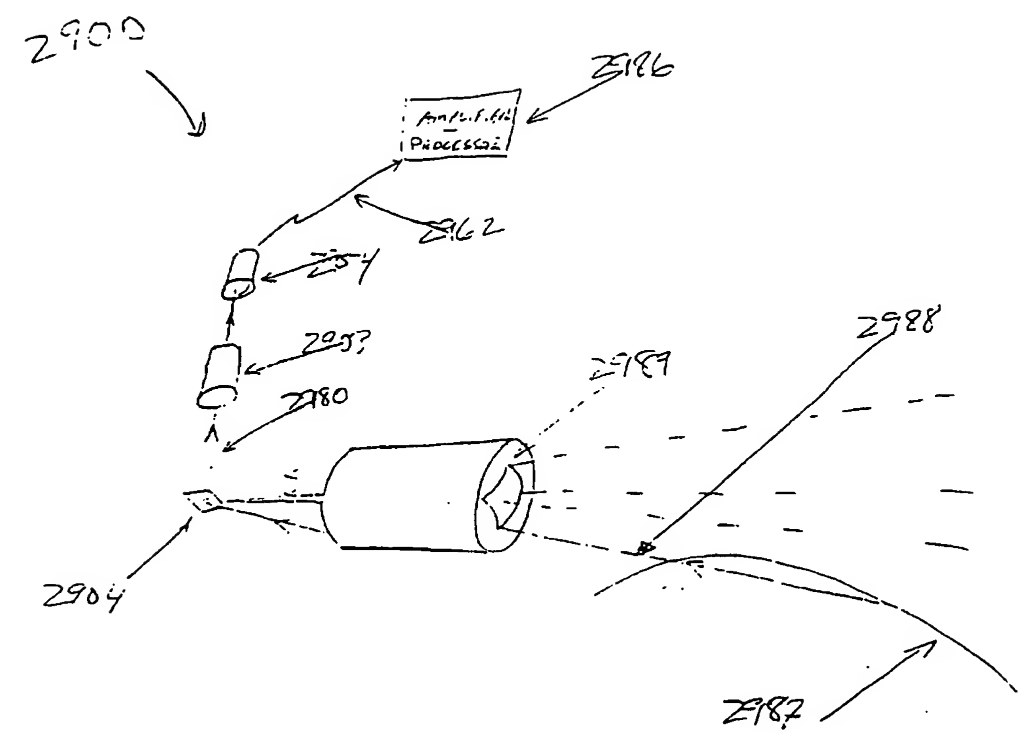
2900
2986
AMPLIFIER PROCESSOR
2962
2954
2952
2989
2988
2980
2904
2987

FIGURE 29

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/17789

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G02B26/08 G02B26/12

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 95 03562 A (MEDCAM INC ;JOHNSON MICHAEL D (US)) 2 February 1995 see page 15, line 425 - page 16, line 461 see figures 1,1A & US 5 673 139 A (JOHNSON) cited in the application ---	1-4,7-20
Y	DE 27 01 730 A (ELEKTRO OPTIK GMBH & CO KG) 20 July 1978 see page 4, line 12 - line 24 see figure 1 ---	1-4,7-9, 13-20
Y	EP 0 729 265 A (BARCO GRAPHICS NV) 28 August 1996 see column 5, line 28 - column 6, line 6 see figure 1 --- -/--	10-12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

2

Date of the actual completion of the international search	Date of mailing of the international search report
21 January 1998	09.02.98

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Luck, W

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	BUSER R A ET AL: "BIAXIAL SCANNING MIRROR ACTIVATED BY BIMORPH STRUCTURES FOR MEDICAL APPLICATIONS" SENSORS AND ACTUATORS A, vol. A31, no. 1 / 03, 1 March 1992, pages 29-34, XP000276408 see chapter 'Introduction' see figure 1 ---	1,2,16, 17,19
A	GB 2 175 705 A (STC PLC) 3 December 1986 see page 1, line 61 - line 89 see figure 1 -----	1

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/17789

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9503562 A	02-02-95	US 5673139 A	30-09-97
		AU 7400894 A	20-02-95
		CA 2166605 A	02-02-95
		CN 1127554 A	24-07-96
		EP 0711422 A	15-05-96
		JP 9502580 T	11-03-97
DE 2701730 A	20-07-78	NONE	
EP 0729265 A	28-08-96	JP 9005655 A	10-01-97
		US 5654817 A	05-08-97
GB 2175705 A	03-12-86	NONE	